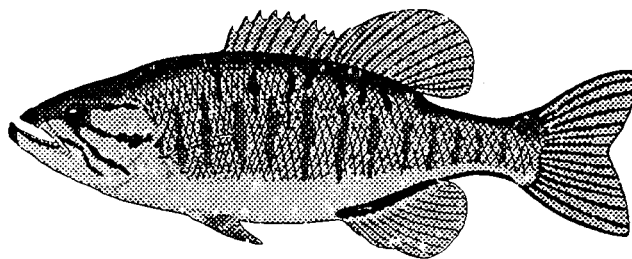


OPTIONS FOR SELECTIVE CONTROL OF NONNATIVE
FISHES IN THE UPPER COLORADO RIVER BASIN



by

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Leo D. Lentsch

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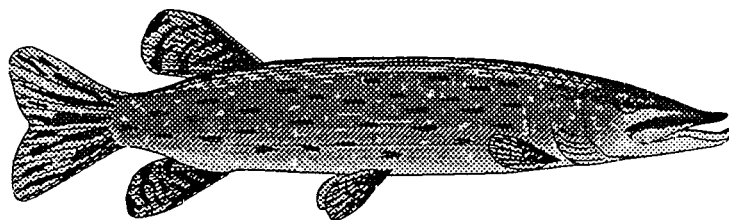
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EXECUTIVE SUMMARY

Introduction and subsequent proliferation of nonnative fishes in the Upper Colorado River Basin (UCRB) have contributed to the decline of many native fishes. There is a need for effective methods to control the abundance and distribution of nonnative fishes throughout the UCRB and reduce the degree of their negative interactions with native fishes. Without these methods, efforts to preserve and possibly recover the endangered fishes will meet with limited success. Nonnative fish families of concern in the UCRB are: Cyprinidae, Catostomidae, Ictaluridae, Esocidae, Centrarchidae, and Percidae.

Objectives of this project were to (1) conduct a comprehensive literature review to evaluate life-history attributes and abiotic and biotic factors that influence the abundance and distribution of each of the 34 nonnative, nonsalmonid fishes in the UCRB, and (2) develop recommendations for methods to reduce the abundance of nonnative fishes, restrict their distributions, and reduce the degree of their negative interactions with the endangered fishes. Both objectives were accomplished. For Objective 1, we reviewed more than 10,000 journal articles, unpublished reports, regional fishery guides, and general fishery biology textbooks to obtain pertinent information about the life history of nonnative fishes in the UCRB and options for controlling their abundance and distributions. Species abundance and life-history requirements were documented and used to make recommendations for controlling

nonnative fishes that are potential or existing threats to endangered or other native fishes in the UCRB (Objective 2).

Physicochemical approaches are the most promising control option for most nonnative cypriniform fishes. Correlative evidence has demonstrated that relative abundance of red shiner *Cyprinella lutrensis*, sand shiner *Notropis stramineus*, fathead minnow *Pimephales promelas*, and redbreasted sunfish *Richardsonius balteatus* is negatively affected by high river discharges and associated lower water temperatures. Selective control of common carp *Cyprinus carpio* and white sucker *Catostomus commersoni* will probably require a combination of physicochemical approaches and mechanical or chemical treatments.

The other nonnative fishes of concern are sport fishes. Mechanical removal is the most promising method to selectively control channel catfish *Ictalurus punctatus* and black bullhead *Ameiurus melas*. Further expansion (e.g., increases in relative abundance) of northern pike *Esox lucius* can be reduced with increased fishing pressure, installation of barriers to prevent downstream movement from reservoirs, and netting and/or electrofishing areas of high concentration. Control measures directed toward centrarchids should begin by reducing their escapement from impoundments. Prevention of future stockings of centrarchids in off-channel habitats or isolating these habitats from river channels would ultimately reduce their abundance throughout the basin. Targeting spawning aggregations for netting, electrofishing, and/or chemical treatment also are

viable mechanical control options for centrarchids. Further expansion of walleye *Stizostedion vitreum vitreum* in the UCRB could be prevented by eliminating future stockings in reservoirs and installing fish barriers to reduce downstream movement from reservoirs.

Key Words: biological control, chemical control, endangered fishes, mechanical control, native fishes, nonnative fishes, physicochemical control, Upper Colorado River Basin

INTRODUCTION

The ichthyofauna of the Upper Colorado River Basin (UCRB) is dominated by nonnative fish species (Table 1). Introduction (either by stocking or accidental release) of nonnative fishes in the UCRB began during the mid to late 1800's (Popov and Low 1950). These introductions were made primarily because early European settlers to the region considered native fish to have little tangible value. Nonnative fishes were initially introduced to supplement food supplies (Popov and Low 1950). Intentional introductions were later made to enhance sport-fishing recreation. For example, in 1970, smallmouth bass were introduced into the lower reaches of the Uinta River, Utah, in order to establish a sport fishery in the Uinta Basin. The introduction was a success, creating the first documented self-sustaining smallmouth bass population in Utah (Mullan 1976). This population is now a source for smallmouth bass in the Duchesne River and the Green River near its confluence with the Duchesne River. In many cases, the recreational benefits identified for reservoir construction also created a demand for introductions (Behnke and Benson 1983). In addition, many introductions of nonnative fishes were made through accidental and/or uncontrolled releases of fish used for bait (Hubbs 1954).

By the early 1980's, 42 (76%) of the 55 fish species occurring in the UCRB were identified as nonnative (Tyus et al.

Table 1.—Nonsalmonid fishes in the Upper Colorado River Basin.

Family	Scientific Name	Common Name
Native Fishes		
Cyprinidae	<i>Gila cypha</i>	humpback chub
	<i>Gila elegans</i>	bonytail
	<i>Gila robusta</i>	roundtail chub
	<i>Ptychocheilus lucius</i>	Colorado squawfish
	<i>Rhinichthys osculus</i>	speckled dace
	<i>Rhinichthys osculus thermalis</i>	Kendall Warm Springs dace
Catostomidae	<i>Catostomus discobolus</i>	bluehead sucker
	<i>Catostomus latipinnis</i>	flannelmouth sucker
	<i>Catostomus platyrhynchus</i>	mountain sucker
	<i>Xyrauchen texanus</i>	razorback sucker
Cottidae	<i>Cottus bairdi</i>	mottled sculpin
Nonnative Fishes		
Clupeidae	<i>Dorosoma petenense</i>	threadfin shad
Cyprinidae	<i>Cyprinella lutrensis</i>	red shiner
	<i>Cyprinus carpio</i>	common carp
	<i>Gila atraria</i>	Utah chub
	<i>Gila copei</i>	leatherside chub
	<i>Hybognathus hankinsoni</i>	brassy minnow
	<i>Hybognathus placitus</i>	plains minnow
	<i>Notropis stramineus</i>	sand shiner
	<i>Pimephales promelas</i>	fathead minnow
	<i>Rhinichthys cataractae</i>	longnose dace
	<i>Richardsonius balteatus</i>	redside shiner
	<i>Semotilus atromaculatus</i>	creek chub
Catostomidae	<i>Catostomus ardens</i>	Utah sucker
	<i>Catostomus catostomus</i>	longnose sucker
	<i>Catostomus commersoni</i>	white sucker
Ictaluridae	<i>Ameiurus melas</i>	black bullhead
	<i>Ameiurus natalis</i>	yellow bullhead
	<i>Ictalurus punctatus</i>	channel catfish
Esocidae	<i>Esox lucius</i>	northern pike
Cyprinodontidae	<i>Fundulus sciadicus</i>	plains topminnow
	<i>Fundulus zebrinus</i>	plains killifish
Poeciliidae	<i>Gambusia affinis</i>	western mosquitofish
Percichthyidae	<i>Morone chrysops</i>	white bass
	<i>Morone saxatilis</i>	striped bass

Table 1.—Continued.

Family	Scientific Name	Common Name
Nonnative Fishes		
Centrarchidae	<i>Lepomis cyanellus</i>	green sunfish
	<i>Lepomis macrochirus</i>	bluegill
	<i>Micropterus dolomieu</i>	smallmouth bass
	<i>Micropterus salmoides</i>	largemouth bass
	<i>Pomoxis annularis</i>	white crappie
	<i>Pomoxis nigromaculatus</i>	black crappie
Percidae	<i>Etheostoma exile</i>	Iowa darter
	<i>Etheostoma nigrum</i>	johnny darter
	<i>Perca flavescens</i>	yellow perch
	<i>Stizostedion vitreum vitreum</i>	walleye

1982). These species also dominate the total number of fish caught. Under present monitoring efforts, over 90% of all fish caught are nonnative (McAda et al. 1994). Behnke and Benson (1983) attributed the dominance of nonnative fishes in the UCRB to dramatic changes in historic flow regimes, water quality, temperature, and habitat characteristics. They noted that water development (e.g., mainstem reservoirs) had converted a turbulent, highly variable river system into one that was relatively stable, with flows and temperature patterns that allowed for the proliferation of nonnative fishes.

Hawkins and Nesler (1991) identified six species on a list of 28 nonnative fishes that were considered by CRB researchers to be of greatest or widespread concern because of their potential impacts on native fishes of the CRB and southwestern United States. These species are red shiner, common carp, fathead

minnow, channel catfish, northern pike, and green sunfish. Other species of increasing concern are sand shiner, white sucker, black bullhead, and largemouth bass. The four cyprinids and channel catfish are considered to be either abundant or common in the UCRB (Table 2) and sympatric with native fishes. The remaining species, although not as common, are primarily considered threats to native fishes due to their increasing abundance (Table 2), habitat preference, and/or piscivorous nature.

Table 2.—Status of nonnative, nonsalmonid fishes in the Upper Colorado River Drainage (modified from Tyus et al. 1982). Status: A=abundant, C=common, R=rare and I=incidental.

Species	River or River Drainage						
	Colorado	Gunnison	Dolores	Green	Yampa	White	San Juan
<i>Dorosoma petenense</i> ^a							
<i>Cyprinella lutrensis</i>	A	C	C	A	C	A	A
<i>Cyprinus carpio</i>	A	C	C	A	C	R	C
<i>Gila atraria</i>				R	I		R
<i>Gila copei</i>				I			I
<i>Hybognathus hankinsoni</i>	I						
<i>Hybognathus placitus</i>							I
<i>Notropis stramineus</i>	C		R	R	C		R
<i>Pimephales promelas</i>	C	C	C	C	C	R	C
<i>Rhinichthys cataractae</i>				R			R
<i>Richardsonius balteatus</i>	I			R	C		R
<i>Semotilus atromaculatus</i>	I			R	R		
<i>Catostomus ardens</i>				R			R
<i>Catostomus catostomus</i>		R					
<i>Catostomus commersoni</i>	R	C	I	I	C ^b		I
<i>Ameiurus melas</i>	R			R	I	I	R
<i>Ameiurus natalis</i> ^a							
<i>Ictalurus punctatus</i>	C	I	C	A	C ^c	R	C
<i>Esox lucius</i>	I	I		I	C ^b	I	R
<i>Fundulus sciadicus</i>						I	
<i>Fundulus zebrinus</i>	I				I		R
<i>Gambusia affinis</i>	I			I			I
<i>Morone chrysops</i>							I
<i>Morone saxatilis</i> ^a							
<i>Lepomis cyanellus</i>	R	I	I	R	I	I	R
<i>Lepomis macrochirus</i>	I			I		I	R
<i>Micropterus dolomieu</i>	I	I		R	I		I
<i>Micropterus salmoides</i>	R	I	I		I		I
<i>Pomoxis annularis</i>							I
<i>Pomoxis nigromaculatus</i>	R	R	R				R
<i>Etheostoma exile</i>							I
<i>Etheostoma nigrum</i> ^a							
<i>Perca flavescens</i>							I
<i>Stizostedion vitreum vitreum</i>				R	I		I

^a Restricted to reservoirs; ^b in upper reaches; ^c in lower reaches

STUDY OBJECTIVES

The purpose of this report is to summarize options for controlling the relative abundance and negative impacts of nonnative fishes on native species in the UCRB and recommend a course of action for implementing those options. Objectives of this project were to (1) conduct a comprehensive literature review to evaluate life-history attributes and abiotic and biotic factors that influence the abundance and distribution of each of the 34 nonnative, nonsalmonid fishes in the UCRB, and (2) develop recommendations for methods to reduce the abundance of nonnative fishes, restrict their distributions, and reduce their negative interactions with the endangered fishes.

METHODS

General procedures were: 1) review and summarize the biology of target species, 2) evaluate control options available to meet constraints of the Colorado River system, 3) recommend appropriate control methods for each species, and 4) recommend appropriate management approaches for the system. This process is similar to that used by aquatic managers successful at selectively controlling undesirable species within aquatic communities. It was based on an extensive literature review.

The literature review consisted of: (1) a review of species-specific journal articles and unpublished reports, and (2) a review of regional fishery guides and general fishery biology textbooks. Document searches were conducted through the CD-ROM fisheries database and other computerized reference databases at Utah State and Colorado State universities. A keyword search for each species (common and scientific name) was completed and printed. This search produced a list of more than 10,000 articles and reports. The list was reviewed and information from over 200 papers, reports, fisheries guides, and textbooks was utilized in the literature review. Documents identified as potentially useful for preparation of this report were collected and reviewed. Following abstract review, documents that were specifically pertinent to the project were copied and reviewed. The majority of documents selected for complete review were available from libraries at the University of Utah, Colorado State University, or the Utah Division of

Wildlife Resources in Salt Lake City. Bibliographies and library catalogs were also examined, which aided in locating species-specific papers and books. The second component of the literature review was reviewing regional fishery guides and general fishery biology textbooks. This information was utilized in summarizing description, distribution, reproduction, habitat, and biology of each species.

In the Species Accounts section, information from the literature review was summarized under eight headings: 1) native distribution, 2) distribution and status in the UCRB, 3) general habitat, 4) examples of environmental factors affecting distribution and abundance (including temperature, flows, dissolved oxygen, pH, salinity, and total dissolved solids), 5) general behavior, 6) reproduction (including maturation, spawning requirements, spawning behavior and biology, and eggs and young), 7) examples of interactions with native CRB fishes, and 8) options for control in the UCRB (including mechanical removal, chemical treatment, biological control, and physicochemical manipulations).

RESULTS

Selective control of undesirable fish is generally defined as actions taken by aquatic managers to reduce numbers or negative impacts of these species within aquatic communities. This reduction does not have to be complete removal, but may be manifested on temporal, spatial, population, and/or community scales (Figure 1). A successful selective-control project requires that negative impacts are reduced and corresponding positive responses from desired species are documented.

Selective-control projects have occurred on a variety of spatial or biological scales. Most chemical treatments are on a small spatial scale such as treatment of small ponds, lakes, or streams to remove undesirable species (e.g., Clemens and Martin 1952; Spitler 1970; Stefferud et al. 1992). However, some chemical-treatment projects have been on large spatial scales. For example, the treatment of Strawberry Reservoir (4,873 ha, 300,000 acre-ft) and associated valley streams (259 km) (Lentsch et al. in press), and the treatment of the Green River (716 km) in 1962 before the closure of Flaming Gorge Dam (Binns 1967) were intended to remove fish species on a community level. Selective-control projects also can focus at a population (single-species) level. For example, Peters (1961) eliminated 80% of the population of gizzard shad *Dorosoma cepedianum* in a Texas lake by rotenone application with only a small percentage of other fish being killed (also see Rose and Moen 1953; Hulsey

Element Factors

Scale	Temporal	Spatial	Population	Community
small	single treatment	local treatment	lifestage	single species
	seasonal influences			
large	multiple or repetitive treatments	treatment of a reach or range	entire population	entire community

Figure 1.—Different scales of fish removal.

1956; Crawford 1957; Pierce et al. 1963; Johnson 1977). Other control projects focus at an age-class or life-stage (e.g., spawning aggregations can be targeted for removal through mechanical means).

Of the selective control projects that we reviewed, approximately 50% were deemed successful by managers that applied the treatments. Generally, the successful treatments followed the process outlined in Figure 2. Aquatic managers reviewed biology of the target species, evaluated available control options that were adequate to overcome the constraints of the systems they were working with, selected an appropriate method, and monitored and evaluated their action. We have followed a similar process for recommending appropriate approaches for selective control nonnative fishes throughout the UCRB (see Figure 3 for a map of the UCRB).

METHODS FOR CONTROLLING FISH

Successful application of methods for selective control of undesirable fishes has challenged aquatic managers for decades. The first documented attempt to control undesirable fish populations occurred in 1914 when copper sulfate was used to chemically treat a Vermont Lake (Titcomb 1914). It was not until the 1930's, however, that the concept of controlling and manipulating composition of fish communities started to be extensively evaluated, developed, and refined. Rotenone (chemical control) was used as a piscicide for the first time in

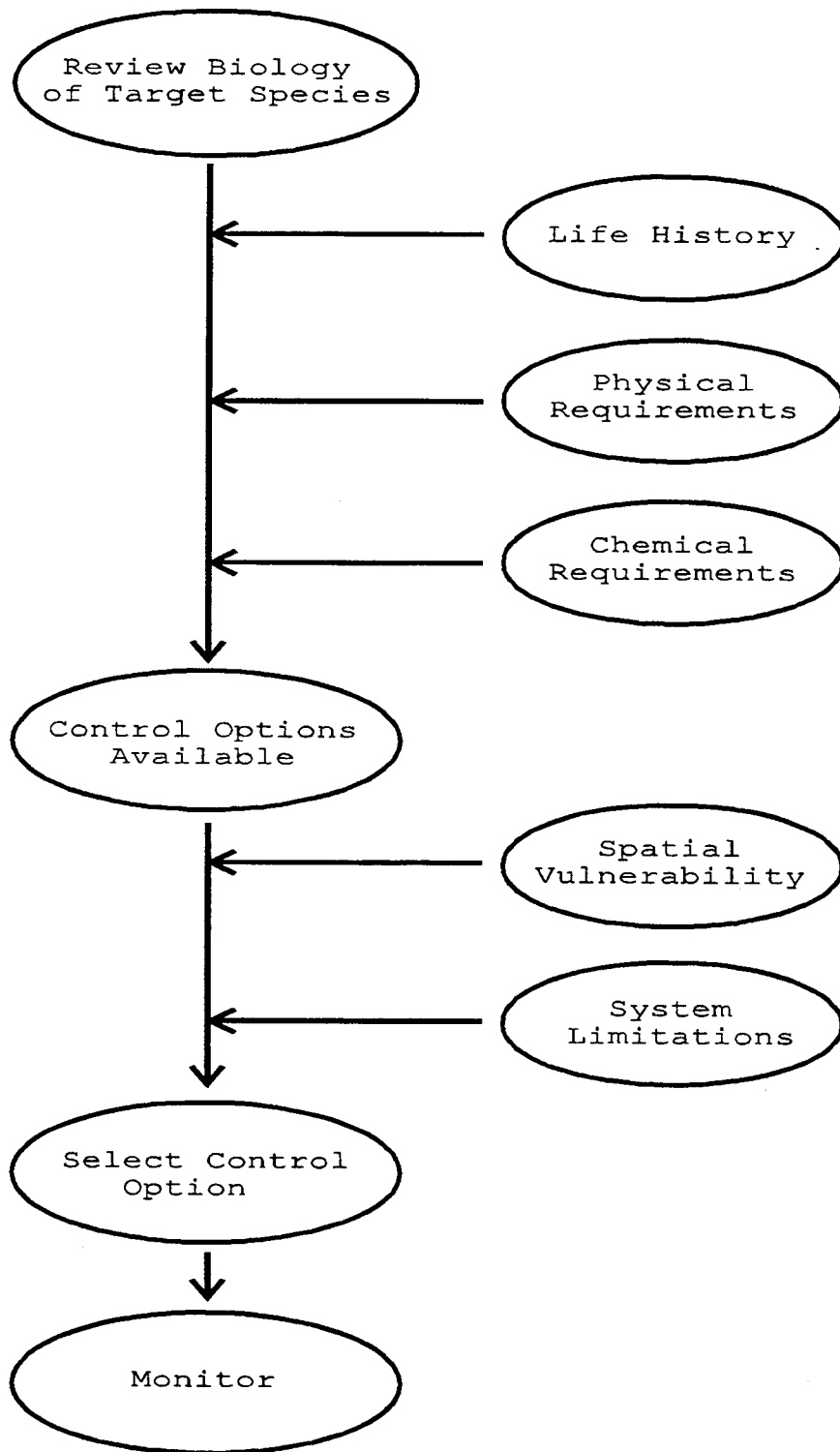


Figure 2.—Process required for successful selective control projects.

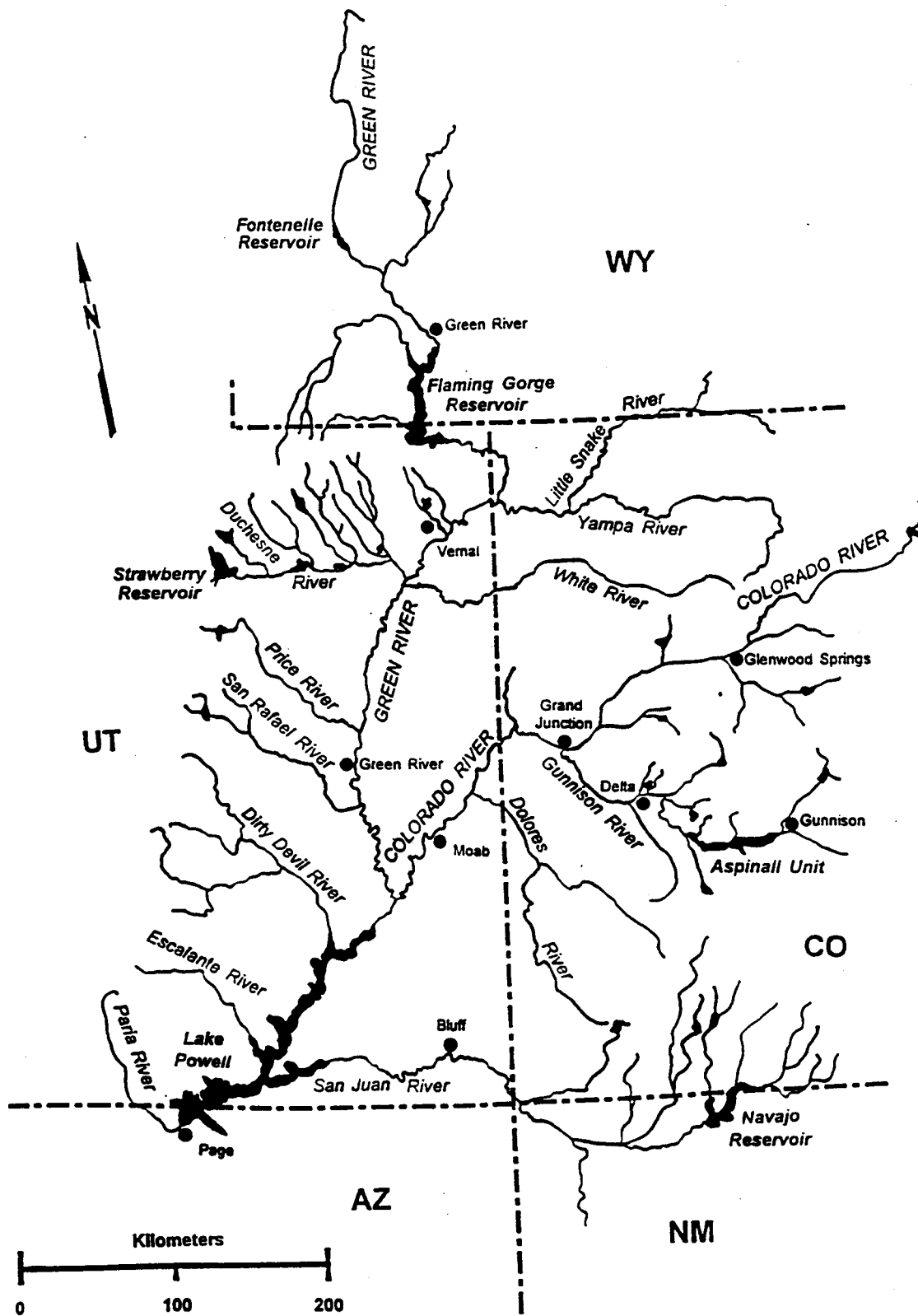


Figure 3.—Map of the Upper Colorado River Basin.

1934 (Hubbs and Eschmeyer 1938). From 1932 to 1938, the first documented mechanical-removal project removed 10,000 northern squawfish *Ptychocheilus oregonensis*, 2,300 trout, 700 dolly varden *Salvelinus malma*, and 700 coho salmon *Oncorhynchus kisutch* with gill nets to enhance the survival of sockeye salmon *Oncorhynchus nerka* (Foerster and Ricker 1941). In 1950, Swingle pioneered the concept of introducing fish species to manipulate an aquatic community to produce a desired state (biological control). One of the first attempts to moderate the physical and chemical habitat that species depend on was attempted through water-level drawdown in a South Dakota reservoir to control common carp (Shields 1958). Generally, four broad categories of fish control methodologies have been developed: 1) chemical, 2) mechanical, 3) biological, and 4) physicochemical.

Chemical Control.—Chemical control has been the most widely used method for controlling fish populations. Schnick (1978) reviewed over 30 chemicals registered as piscicides. At least 10 different chemicals have been used extensively in the United States for this purpose, i.e., copper sulfate, rotenone, toxaphene, endrin, antimycin, TFM (trifluoromethyl-nitrophenol), sodium cyanide, squoxin, bayluscide, and thanite (Cumming 1975). Only four of these chemicals (rotenone, antimycin, TFM, and bayluscide) are currently registered for use in North America (Wiley and Wydoski 1993). In 1914, copper sulfate was the first chemical used to control undesirable fish (Titcomb 1914). In

1934, rotenone was used in the United States for the first time as a piscicide (Hubbs and Eschmeyer 1938). From 1940 to 1970, chemical-control projects were prolific throughout North America. Efforts to identify selective toxicants were initiated in the 1950's and had limited success. The notable selective chemicals are TFM for sea lamprey (Applegate et al. 1961) and squoxin for northern squawfish (MacPhee and Ruelle 1969). Lennon et al. (1970), Cumming (1975), Schnick (1974a, 1974b), and Bradbury (1986) have thoroughly summarized the history and use of chemicals for control projects.

Most chemical-control projects have focused on small streams, ponds, or lakes/reservoirs with varied success. Rosenlund (in prep.) and Lentsch et al. (in prep.) identified procedures for successfully treating streams. Gresswell (1991) was successful in eradicating brook trout *Salvelinus fontinalis* from Arnica Creek, a third-order tributary of Yellowstone Lake, Wyoming. Stefferud et al. (1992) found that chemical treatment eradicated nonnative trouts from streams of native gila trout *Oncorhynchus gilae*. However, at least two consecutive years of poisoning was required in both cases. Other studies have found that chemical toxicants have reduced, but not eradicated, fish populations in streams (Rockett 1975; Leppinik 1977; Avery 1978).

Lennon et al. (1970) identified five major factors involved with success or failure of a chemical-control project in ponds, lakes, or reservoirs: (1) water chemistry, (2) toxicant, (3) formulation of toxicant, (4) differential toxicity to various

fish species, and (5) method and thoroughness of application. Wollitz (1962) reported a complete fish kill in a 5.2-ha Montana pond after using rotenone at a concentration of 0.7 mg/L. Clemens and Martin (1952) treated 18 Oklahoma ponds (surface area ranged 1000 m² to 1.7 ha) with rotenone (concentrations ranged 0.5-3.5 mg/L) to eradicate all fish. Complete elimination of fish, however, was achieved in only two ponds, and in one case only after a second treatment at 2 mg/L. In 15 of the 16 ponds exhibiting an incomplete fish kill, only age-0 fish were present after treatment, indicating that eggs and/or fry survived the treatment.

Lakes and reservoirs have been successfully chemically treated. Borovicka (1961) applied toxaphene (concentrations ranging 0.01-0.1 mg/L) to 10 lakes and reservoirs (surface area ranging 1.6 ha to 6.1 km²) and 5% liquid rotenone to tributaries. A complete kill resulted from six of the treatments. Smith (1959) reported that gizzard shad were drastically reduced in three reservoirs (surface area of 43 ha to 14.6 km²) and completely eliminated from a fourth (surface area 28 ha) after applying rotenone at an average concentration of 0.1 mg/L. Spitler (1970) found that complete kills resulted in 34 of 84 Michigan lakes (surface area of 1600 m² to 2.2 km²) after they were treated with rotenone (concentrations ranged 0.5-10 mg/L). Barrows (1939) reported a complete fish kill in Goose Lake (surface area 30 ha), Yellowstone National Park after treatment with 245 kg of derris root (5% rotenone). Tanner and Hayes

(1955) reported a complete fish kill in a Colorado reservoir (surface area of 40.5 ha) by using toxaphene at a rate of 0.1 mg/L.

Some chemical-control projects have resulted in selective removal of species. Peters (1961) reported that 80% of the gizzard shad population was eliminated in a Texas lake (surface area not given) after treatment with 5% rotenone powder. Only a small percentage of other fish were killed. Dietz and Jurgens (1963) also reported that 76 kg/ha of gizzard shad and common carp was removed from a Texas lake (surface acres of 23.1 km²) by chemical treatment (rotenone at a concentration of 0.13 mg/L) with a minimal loss of gamefish. Antimycin was applied to a 1.9-ha pond in Wisconsin at a concentration of 10 µg/L. Common carp (as well as other species) were reduced, whereas channel catfish and black bullhead were not affected (Berger 1965).

Although most chemical-reclamation projects have focused on small bodies of water and streams, large-scale chemical-reclamation projects have been attempted. In 1962, before Flaming Gorge Dam was closed, 716 km of the Green River and its tributaries were treated with 81,681 L of 5% rotenone. Fish were virtually eliminated following treatment, but by 1964, flannelmouth sucker, redbreast shiner, fathead minnow, and speckled dace had reached pretreatment distributions (Binns 1967). Chemical reclamation of Strawberry Valley was completed in 1990. The treatment involved applying 398,258 kg of powdered rotenone to Strawberry Reservoir (4,873 ha, 300,000 acre-ft) and 9,470 L

of liquid rotenone to 259 km of streams. This project met all of its objectives and has been considered a success (Lentsch et al. in press).

Mechanical Control.—Mechanical-removal methods include traps, seines, gill nets, barriers, electrofishing, and harvesting (commercial and recreational). Species in the families Cyprinidae, Catostomidae, Centrarchidae, and Percidae are fishes most commonly targeted for control by mechanical methods in the United States. Combinations of control methods may be necessary to reduce different age classes of a species or reduce target species when they are most vulnerable to particular methods (Wiley and Wydoski 1993).

Mechanical-removal efforts are often attempts to thin populations of undesirable fishes to improve the size structure of gamefish populations. Rose and Moen (1953) reported an increase in numbers of game fish in East Okoboji Lake, Iowa, after intensive removal of nongame fishes. Pierce et al. (1963) also reported a positive response in populations of gamefishes after removal of golden shiner *Notemigonus crysoleucas* by netting from a lake in Georgia. Crawford (1957) and Hulsey (1956) documented an increase in numbers and weight of gamefish after removal of 93,000 kg of undesirable fishes in Lake Nimrod, Arkansas.

Mechanical removal of undesirable fishes, however, does not necessarily improve populations of gamefishes (i.e., Hacker 1952;

Threinen 1952; Scidmore and Woods 1961). Over 3 years, Huish (1959) removed 162,364 kg of fish by seining in Lake Reedy, Florida, but had no effect on catch of sport fishes by anglers. Rawson and Elsey (1950) removed 27,597 longnose sucker with gill nets and wire-mesh traps from Pyramid Lake, Alberta. Although the age structure of longnose sucker was altered, the fishery for rainbow trout *Oncorhynchus mykiss* did not improve. Scidmore (1960) did not observe an increase in average size of bluegill after removal of undesirable fishes by seining and trap-netting in two Minnesota lakes.

Commercial and recreational fishing has been used to selectively reduce fish populations. Donald and Alger (1989) reported that fish in a population of stunted brook trout increased in maximum weight from 68 g to 158 g after the population was exploited at an annual rate of 20% fishing mortality for 3 years. In Lake Traverse, Minnesota and South Dakota, weight of common carp per seine haul decreased from 11,757 kg to 231 kg after 13 years of commercial fishing for the species with hoopnets and seines (Moyle and Clothier 1959). In an Ohio lake, fishing regulations were liberalized to reduce undesirable fish and improve the size structure of populations of bluegill and largemouth bass (Pelton 1948).

Mechanical removal attempts have met with varying success because only a portion of the population is typically removed. A large percentage of fish in the target population must be removed to achieve partial/temporary control. In a northeastern

Minnesota lake, Johnson (1977) was able to remove 85% of the estimated standing crop of adult white sucker by trap-netting during the spring of 1966; recovery of the population through recruitment was not evident until 1972. However, in 14 Minnesota lakes, Moyle et al. (1950) found that 25 years of seining did not reduce populations of undesirable fishes. They estimated that only one-third of targeted fish was removed each year.

Biological Control.—Biological control methods can be grouped into three categories: (1) grazing and predation by protozoa, zooplankton, fish, birds, insects, snails, crayfish, turtles, and mammals; (2) use of pathogens (viruses, bacteria, and fungi); and (3) biomanipulation, which adjusts interrelationships among plants, animals, and their environment to achieve the desired control or ecological balance (Wiley and Wydoski 1993). For purposes of this report, we included the prevention of additional introductions and stocking under biological control.

Biological control of fish and aquatic plants is becoming increasingly popular with fisheries-management agencies. Biomanipulation is the most promising biological-control technique because it has the potential to minimize competition and establish balanced predator-prey populations (Wiley and Wydoski 1993). However, because biomanipulation often requires the introduction of predator or prey species, it is only addressed in this paper when native fishes can be manipulated.

Pathogens have successfully reduced fish abundance. The channel catfish virus disease (CCVD) impacts only channel catfish. Young are particularly vulnerable to this highly communicable, selective disease, which can be fatal 50-95% of the time (Plumb et al. 1989).

Physicochemical Control.—Control of undesirable fishes also can be achieved with physicochemical approaches, including the manipulation of water levels, temperature, flow, and turbidity. Many authors have suggested that nonnative fish species became established in the western United States at least partly because historic flow regimes were modified to resemble flows that favor these species. A return to larger, historic amplitudes in seasonal discharge may allow native fishes to better compete with nonnative fishes (McAda and Kaeding 1989a).

Meffe (1984) reported that the Sonoran topminnow *Poeciliopsis occidentalis*, a native to the arid southwest, was most rapidly replaced by mosquitofish in areas that rarely flooded, and long-term coexistence of the two species may occur in areas that frequently flood. Minckley and Meffe (1987) found that nonnative fishes (i.e., common carp, red shiner, fathead minnow, ictalurids, mosquitofish, largemouth and smallmouth bass, green sunfish, and bluegill) were reduced in abundance or completely eliminated after major flooding in unregulated Arizona streams, whereas abundance of native fishes was rarely affected.

Nonnative cyprinids (red shiner, sand shiner, fathead minnow, and redbside shiner) also are affected by flow manipulations. Osmundson and Kaeding (1989) noted a marked increase in the abundance of red shiner, fathead minnow, and sand shiner during a 3-year study in the Grand Valley (Loma and Palisade) during which spring peak and summer flows progressively declined. McAda and Kaeding (1989a) found that the more common nonnative cyprinids in the upper Colorado River (Green River confluence to Grand Junction) were in greatest abundance in summers following low spring flows and were in lowest densities during periods following high spring flows. In the Yampa River, 1980-1984, Muth and Nesler (1993) found that earlier initiation of spawning and higher catch-per-unit-effort (CPUE) for nonnative cyprinids, and longer spawning seasons for red shiner, sand shiner, and fathead minnow were generally associated with low peak discharge and low-moderate daily mean and total discharges. Conversely, later initiation of spawning and lower CPUE for nonnative cyprinids, and shorter spawning seasons for red shiner, sand shiner, and fathead minnow were associated with high peak discharge and moderate-high daily mean and total discharges. Correlative evidence between discharge and cyprinid abundance suggests that high flows flush nonnative cyprinids from their preferred lentic habitats, resulting in local reductions in their abundance and reproductive success (Valdez 1990).

Physicochemical control of fish species through water level manipulations in reservoirs has been successful. Various fishes,

such as sunfish, minnows, suckers, perch, pike, pickerel, and carp spawn in shallow waters. By controlling the water level at times when these species spawn, reductions in their population are possible. Davis and Hughes (1964, 1968) and Lantz et al. (1964) reported that water-level drawdown in Bussey Lake, Louisiana, resulted in removal of 95% of the macrophytes and a reduction in nuisance fish. Shields (1958) reported that common carp reproduction was negatively impacted by water-level drawdowns in a South Dakota reservoir. Water-level manipulations in arid and semi-arid regions are more difficult because water is a precious commodity used for irrigation and domestic or industrial uses (Wydoski 1990).

Selective control of the 34 nonnative, nonsalmonid fish species in the UCRB may be assessed through these methods. Understanding the life history requirements of these nonnative fishes will be critical for reducing their abundance (summarized in Species Accounts and Table 3). We present particular control options or combinations of methods that appear best suited at reducing the abundance of these species (summarized in Species Accounts and Table 4). Furthermore, targeting groups of species and/or habitats when nonnative species are abundant will optimize time and effort involved for control (Wiley and Wydoski 1993).

SPECIES ACCOUNTS

Clupeidae-Herrings

Threadfin Shad *Dorosoma petenense*

Native Distribution:

Gulf of Mexico from Florida south to Guatemala and Belize and north into Oklahoma and Texas [Carlander 1969].

Distribution and Status in Upper Colorado River Basin:

Widely introduced as a forage fish in warmer climates [Lee et al. 1980]. The threadfin shad is an important forage fish for piscivorous game species in freshwater lentic habitats of the central and southern United States [Carlander 1969; Griffith 1978]; controversy over whether introducing threadfin shad is beneficial or deleterious to game species [Guest et al. 1990]. First introduced into Lake Powell in 1968, now abundant throughout the lake and enters tributary inflow areas; not reported elsewhere in the UCRB [Tyus et al. 1982].

General Habitat:

Inhabit lakes, ponds, reservoirs, large rivers, and estuaries [Lee et al. 1980]. Prefer pelagic zones of reservoirs [Tyus et al. 1982].

Examples of Environmental Factors Affecting Distribution or Abundance:

■ Primary limiting factor is temperature (need warm water); other limiting factors are over-crowding and a lack of plankton for food [Johnson 1970].

Temperature.—

■ Critical thermal minimum is 4°C with extremely high mortality occurring when temperatures drop suddenly, especially below 12°C. Threadfin shad acclimated to 15°C experienced 50% mortality when exposed to 5°C for 1 h and 100% mortality when exposed to 4°C for 3 h [source unknown].

Salinity.—

■ Prefer brackish water with salinity concentrations of 12-20 ppt [Carlander 1969].

General Behavior:

A schooling, pelagic fish. Primarily planktivorous but also consumes benthic invertebrates, detritus, fish eggs, and occasionally fish larvae [Gerdes and McConnell 1963; Ingram and Ziebell 1983].

Reproduction:

Maturation.—Mature at 1-2 or 2-3 years of age. Most do not live past 2 years, but have been reported to live up to 3-4 years. Maximum length 175-200 mm [Carlander 1969; Johnson 1970; Sublette et al. 1990].

Spawning Requirements.—Spawn in spring (May-June) and possibly fall (September-November) [Carlander 1969; McLean et al. 1982]. Water temperatures during spawning range 14-23°C. Spawn in open water or near shore over aquatic plants [Carlander 1969; McLean et al. 1982; Sublette et al. 1990].

Spawning Behavior and Biology.—Synchronous, group spawner. Eggs are randomly deposited over a 3 to 4-week period in vegetated areas [Carlander 1969; McLean et al. 1982; Sublette et al. 1990]. Often spawn in early morning to avoid predation [McLean et al. 1982]. Reported fecundity ranges 900-25,000 eggs, depending on size of female [Sublette et al. 1990].

Eggs and Young.—Eggs are adhesive and have a maximum diameter of 0.75 mm. Incubation period is 3 d at 27°C. Total length at hatching is 4.1-4.4 mm. Larvae exhibit diel vertical migrations; near surface in daytime, dispersed through midwater and near bottom at night [Burns 1966; Taber 1969].

Examples of Interactions with Native Colorado River Basin Fishes:

■ None found.

Options for Control in the Upper Colorado River Basin:

Not considered a threat to the endangered fishes. Threadfin shad in the UCRB are restricted to Lake Powell and inflow areas; winter water temperatures in other parts of the basin are too cold. Threadfin shad constitute the primary food source for piscivorous fishes in Lake Powell that could prey on native fishes.

Cyprinidae-Carps and Minnows

Red Shiner *Cyprinella lutrensis*

Native Distribution:

Mississippi and Gulf drainages, from South Dakota through Illinois and from Louisiana westward into northern Mexico [Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

First collected in the Lower Colorado River Basin south of Gadson, Arizona, in 1953 (fish probably escaped from a bait farm near Ehrenburg, Arizona) [Hubbs 1954]. Possibly first introduced into the UCRB near Grand Junction in the late 1950's or early 1960's [Holden and Stalnaker 1975]. Spread rapidly throughout the Colorado River and tributary streams where it is now common or abundant [Minckley 1973; Moyle 1976; Gleason 1982; Tyus et al. 1982; Sublette et al. 1990; Hawkins and Nesler 1991].

Widespread, common or abundant (possibly the most abundant fish species in the upper basin). Principal distribution is in middle and lower sections of larger rivers having warm and usually turbid water. Predominant species in low-velocity nursery habitats of native fishes (all life stages of red shiner occur in these habitats) [Tyus et al. 1982; Haines and Tyus 1990; Karp and Tyus 1990a; Ruppert et al. 1993; Nelson et al. 1995].

In a survey of CRB researchers, red shiner ranked second on a list of 28 nonnative fish species considered to adversely impact native fishes of the CRB and the southwestern United States. Suspected impacts included predation on larvae of native fishes, especially Colorado squawfish and razorback sucker, and competitive interactions with young of native fishes, especially Colorado squawfish and *Gila* sp. [Hawkins and Nesler 1991].

General Habitat:

Mobile, aggressive, generalist species (adapts well to new habitats). Primarily a riverine species but occurs in impoundments. Found in streams of all sizes but most abundant in moderate- to large-sized creeks and rivers with low gradient and low to moderate water velocities. Inhabit a variety of perennial and ephemeral riverine habitats (including quiet pools, backwaters, mouths of creeks, runs, and riffles) with a variety of substrate types (silt, sand, gravel, boulders). Adaptable and tolerant of high turbidity and siltation and fluctuations in flow, temperature,

dissolved oxygen (D.O.), pH, and salinity (thrive in unstable environments). Avoid areas that are continuously clear or cool; uncommon or absent in clear, high-gradient streams [Baxter and Simon 1970; Minckley 1973; Cross and Collins 1975; Pflieger 1975; Moyle 1976; Matthews and Hill 1979b; Smith 1979; Lee et al. 1980; Phillips et al. 1982; Tyus et al. 1982; Becker 1983; Gale 1986; Robison and Buchanan 1988; Rutledge and Beitingger 1989; Haines and Tyus 1990; Sublette et al. 1990].

Examples of Environmental Factors Affecting Distribution or Abundance:

- Considered a pioneer species, moving into new, disturbed, or marginal habitats where other fishes are rare [Harlan et al. 1987].
- In waters of the San Joaquin Valley, California, abundance of red shiner was positively correlated with turbidity, pH, conductivity, total alkalinity, total hardness, total dissolved solids, percentage of runs, and human impacts, and negatively correlated with maximum stream depth and width [Jennings and Saiki 1990].
- In the South Canadian River and Pond Creek, Oklahoma, water temperature, velocity, and depth were the most important variables in habitat selection (low-velocity water deeper than 20 cm with pH 7.1-7.4 was consistently selected; avoided temperature extremes in winter and summer but adaptable to wide thermal variations). D.O., turbidity, shelter, shade, and substrate type were lesser in importance [Matthews and Hill 1979b].
- In the South Canadian River, compared to adults, juveniles selected higher temperatures, higher D.O. concentrations, higher pH, lower total dissolved solids, lower turbidity, and more stable substrates. Compared to juveniles, adults occupied deeper water and locations with more shelter and shade. Both life-period groups selected the slowest water velocities available [Matthews and Hill 1979a].
- In a survey of 101 stream locations within a major portion of the red shiner's native range, most abundant in streams with few other fishes, turbid water, muddy substrates, and unstable banks. Most often uncommon or absent in areas with high numbers of other fishes, clear water, abundant algae, rocky substrates, and stable banks [Matthews 1985]. Depauperate native fish fauna of western United States may give red shiner a competitive advantage [Rinne 1991].

■ Within native range, rarely becomes abundant in clear streams with constant flow and substantial populations of other minnows. Abundance increases when flows decrease and abundance of other fishes is reduced [Minckley 1973]. Competition from other fishes, especially other minnows, may be an important factor in controlling red shiner distribution within its native range [Pflieger 1975].

■ Possible reasons for the success of red shiner: (1) small in size (only limited space and resources are necessary to sustain populations); (2) occur in schools; (3) active, move rapidly into accessible waters; (4) short lived, mature rapidly, and produce large numbers of young; and (5) extremely tolerant of adverse conditions [Cross and Collins 1975].

■ During dry years, red shiner may predominate in streams having high gradients, whereas other fishes decline. In the first year or two of a wet cycle, red shiner may continue to be abundant and occupy nearly all available habitats. If the wet cycle continues, red shiner may decline in abundance until only residual numbers remain [Cross 1967].

Temperature.—

■ For fish from the South Canadian River, acclimated at 25°C, mean critical thermal maximum (CTM) was 38.99°C (range 38.70-39.20°C); highest CTM of minnows tested. Success of red shiner more closely related to CTM than tolerance to low D.O. conditions [Matthews and Maness 1979].

■ No clinal trends in CTMs among populations of red shiner from 18 river locations including most major drainages within the native range of the species in the American Great Plains (at an acclimation temperature of 21°C, CTMs ranged 35.90-36.35°C); CTMs among populations unrelated to stream size [Matthews 1986].

■ Fish from Quapaw Creek and Walnut Creek, Oklahoma, acclimated at 24-28°C, survived thermal shocks of +10 to -21°C (shocks of \geq +12°C and -24°C were lethal); survived larger negative than positive thermal shocks [Matthews and Hill 1977].

■ For fish from Denton Creek, Texas, acclimated at 30°C and with access to the surface, CTMs at three D.O. concentrations were 35.45°C (1.2 ppm, hypoxic), 39.65°C (7 ppm, normoxic), and 39.12°C (12 ppm, hyperoxic). Other data suggested that temperature tolerance was

independent of D.O. at concentrations as low as 2.0 ppm (critical oxygen concentration for upper temperature tolerance between 1.2 and 2.0 ppm) [Rutledge and Beitinger 1989].

- For fish from the Brazos River, Texas, collected above and below a reservoir, selected median water temperature ranged 23.0-30.9 and 21.2-28.5°C for the two populations, respectively, and final temperature preferenda were 30.0 and 23.3°C, respectively [Calhoun et al. 1982].

- For fish from the Virgin River, Utah-Nevada-Arizona, preferred mean water temperatures were 12, 22, and 27°C and calculated CTMs were 30.10, 33.07, and 38.80°C at respective acclimation temperatures of 10, 15, and 25°C; CTMs provide insight into distributional patterns (thermally labile species) [Deacon et al. 1987].

- Classified as having high thermal tolerance, nonselectivity in thermal gradients, and adaptive Type 1 traits (i.e., adapted to harsh environments and relatively nonselective within physicochemical gradients) [Matthews 1987].

Flow and Temperature.—

- For fish in the Yampa River, 1980-1984, earlier initiation of spawning, longer spawning season, and higher catch-per-unit-effort (CPUE) of age-0 individuals were associated with low peak discharge, low to moderate daily mean and total discharges, and moderate to high numbers of cumulative degree-days. Conversely, later initiation of spawning, shorter spawning season, and lower CPUE were associated with high peak discharge, moderate to high daily mean and total discharges, and low to moderate numbers of cumulative degree-days [Muth and Nesler 1993].

- For fish in the Colorado (Colorado and Utah) and Gunnison rivers, moderate to significant inverse relationships were noted between magnitude of discharge and abundance of red shiner [McAda and Kaeding 1989a; Osmundson and Kaeding 1989, 1991; Valdez 1990].

- In Green River, Utah, 1979-1988, most abundant in backwaters > 15 cm deep and having cooler water temperatures (< 22.5°C). CPUE decreased with increasing summer flows [Haines and Tyus 1990].

- Flooding in unregulated streams of Arizona and New Mexico depleted or removed red shiner but rapidly reestablished substantial populations through survivors, reinvaders, or direct reintroduction [Minckley and Meffe 1987].

Dissolved Oxygen.—

- Fish from Quapaw Creek and Walnut Creek, survived D.O. concentrations of 1.5 ppm (≤ 1.0 ppm were lethal) [Matthews and Hill 1977].
- Classified as having high tolerance to low D.O., selectivity in D.O. concentration gradient, and adaptive Type 1 (see temperature) and Type 2 traits (i.e., adapted to harsh environments and having less width of tolerance but more acutely selective than Type 1 animals and more closely track optimal physicochemical conditions) [Matthews 1987].

Hydrogen Ion Concentration (pH).—

- Fish from Quapaw Creek and Walnut Creek survived pH of 5-10 (pH ≤ 4.0 and ≥ 11.0 were lethal) [Matthews and Hill 1977].
- Fish in the South Canadian River selected water with pH 7.1-7.4 [Matthews and Hill 1979b].

Salinity.—

- Fish from Quapaw Creek and Walnut Creek survived salinities of ≤ 10 ppt (≥ 11 ppt were lethal) [Matthews and Hill 1977].

General Behavior:

Live in schools in midwater or near the surface. Reported nocturnal movement from deep water into shallow water and to the surface. During daylight, fish found on the bottom or in midwater [Mendelson 1972]. Under laboratory conditions, red shiners were strongly attracted to water previously occupied by conspecifics; olfaction hypothesized as a cue in habitat selection [Asbury et al. 1981].

Feed primarily by sight [Pflieger 1975]. Morphologically best suited for feeding on small invertebrates in midwater and aquatic plants in quiet water. Feed mostly during daylight but may peak in feeding activity at dawn [Moyle 1976]. Omnivorous, consume primarily aquatic or terrestrial insects, small crustaceans, algae, aquatic vegetation, and possibly small fish [Kosher 1957; Carlander 1969; Baxter and Simon

1970; Laser and Carlander 1971; Minckley 1973, 1982; Cross and Collins 1975; Pflieger 1975; Smith 1979; Woodling 1981; Gleason 1982; Becker 1983; McAda and Tyus 1984; Harlan et al. 1987; Greger and Deacon 1988; Robison and Buchanan 1988; Jennings and Saiki 1990; Sublette et al. 1990; Ruppert et al. 1993].

Reproduction:

Maturation.—Typically mature as yearlings (age 1); ≥ 40 mm total length (TL). Attain a maximum length of 76-102 mm [Beckman 1952; Koster 1957; Carlander 1969; Baxter and Simon 1970; Laser and Carlander 1971; Pflieger 1975; Farringer et al. 1979; Smith 1979; Phillips et al. 1982; Harlan et al. 1987]. Few individuals live beyond age 2. In Oklahoma and Texas, growth of adults most rapid from March through June; growth slow in summer due to higher temperatures and reproductive activity [Farringer et al. 1979].

Spawning Requirements.—Very adaptable in spawning requirements. Spawn in both streams and lakes. Spawn over gravel or sand in riffles, over submerged logs, roots, or vegetation, along rocky shorelines in crevices, or in nests of other fishes [Sakensa 1962; Cross 1967; Taber 1969; Minckley 1973; Pflieger 1975; Smith 1979; Woodling 1981; Gale 1986]. Plasticity in choice of spawning substrate may partially explain success of red shiner and rapid spread in western United States [Vives 1993].

Reported spawning-season and water-temperature ranges were March-September, 15.5-31.7°C. In Missouri, spawn late May-early September with peak spawning occurring in June and July [Pflieger 1975]. In Iowa, spawn May-August with peak spawning occurring in May or early June [Harlan et al. 1987]. In Oklahoma and Kansas, spawn June-August (maybe May-September) with peak spawning occurring in June and July [Carlander 1969; Taber 1969; Cross and Collins 1975; Farringer et al. 1979]. In Arizona, spawn March-June [Minckley 1972]. In Wyoming and eastern Colorado, spawn in June and July [Beckman 1952; Baxter and Simon 1970]. In the Yampa River, 1980-1984, spawned late May-mid September [Muth and Nesler 1993]. Water temperatures $> 30^{\circ}\text{C}$ may inhibit spawning or may be lethal to incubating eggs [Farringer 1979; Gale 1986].

Spawning Behavior and Biology.—Spawn primarily during morning daylight hours; male establishes spawning territory (see [Minckley 1972, 1973; Gale 1986] for description of courtship and spawning behavior). Observations made under controlled conditions showed that red shiner is a fractional (over one clutch per season), crevice spawner. Each female may produce several clutches (5-19) of eggs per season with an average of 585 eggs per clutch (range = 131-1,661 per clutch) [Gale 1986]. Spawning frequency and fecundity likely

temperature dependent, each increasing with increased temperature [Gale 1986]. Reported number of eggs per gravid female ranged 1,177-5,411 (mean 2,205) [Jennings and Saiki 1990].

Eggs and Young.—Eggs are demersal, adhesive, and have a maximum diameter of 1.0-1.3 mm. Incubation time is 3-5 d at water temperatures of 21-28°C [Taber 1969; Gale 1986]. Total length at hatching is 4 mm [Snyder 1981]. Estimated daily growth of larvae and early juveniles is 0.2-0.3 mm [Carlson et al. 1979]. Estimated TL at end of first year is ≤40 mm [Carlander 1969]. In Oklahoma and Texas, young-of-year exhibited rapid growth in summer and slow growth in September-March [Farringer et al. 1979].

Examples of Interactions with Native Colorado River Basin Fishes:

- Contributed significantly to decline of native fishes in Arizona [Minckley 1973].
- Associated with decline of native fishes in the Moapa River, Nevada [Deacon and Bradley 1972].
- In the Virgin River, competition for food between red shiner and woundfin *Plagopterus argentissimus* may occur. Relatively high diet overlap was demonstrated between speckled dace and red shiner [Greger and Deacon 1988].
- Habitat partitioning may occur when spikedace *Meda fulgida* and red shiner co-occur in a stream [Rinne 1991].
- Predation on cypriniform larvae (mostly catostomids, some identified as bluehead sucker by adult red shiner during early summer 1991 was documented in ephemeral shoreline embayments near confluence of the Yampa and Green rivers [Ruppert et al. 1993]. Hypothesized that if predation by red shiner on fish larvae is in part a function of availability of alternative invertebrate prey, and if abundance of preferred invertebrate forage is lower during spring and early summer in at least some nursery habitats, early larvae of razorback sucker may be especially vulnerable.
- In the Green River, Utah, 1980, high habitat-use overlap (index value of 0.90) between age-0 Colorado squawfish and red shiner. High diet overlap (index values ranged 0.7-0.8) between Colorado squawfish 22-40 mm TL and all sizes of red shiner examined. Colorado squawfish 41-59 mm TL fed heavily on red shiner larvae [McAda and Tyus 1984].
- In the Colorado and Green rivers, Colorado and Utah, habitats of age-0 Colorado squawfish and red shiner overlapped [McAda and Kaeding 1989b].

■ In the Green River, Colorado and Utah, 1987, biologically important diet overlap (index values > 0.60) occurred between age-0 Colorado squawfish and red shiner and was primarily attributed to the high relative importance of immature midges in diets of both species. Larval red shiner were identified in guts of some age-0 Colorado squawfish [Muth and Snyder 1995].

■ Observations on behavioral interactions under laboratory conditions suggested that in shared habitats, red shiner may adversely affect growth and survival of age-0 Colorado squawfish [Karp and Tyus 1990a].

■ Under laboratory conditions, adult red shiner ate larvae of Colorado squawfish and razorback sucker. Predation rate and efficiency decreased as larvae developed, during darkness, in the presence of alternative invertebrate prey, and in turbid water [R. Muth and D. Beyers, unpublished data].

■ About 5% of 433 adult red shiner collected from the Colorado and Green rivers, Canyonlands National Park, Utah, in spring and early summer 1994 had larval fish in their guts. Larvae were identified as cypriniform and most were catostomids (species undetermined because larvae were too digested for accurate identification) [R. Muth, unpublished data].

Options for Control in the Upper Colorado River Basin:

Controlling or limiting red shiner will be difficult because of its extremely high abundance, ubiquitous distribution, high adaptability, high reproductive potential, and ability to rapidly re-colonize.

Mechanical Removal.—Partial, temporary removal might be achieved by periodic seining of selected low-velocity habitats. Blocking access of adult red shiner to portions of low-velocity habitats in the lower Green River, Canyonlands National Park, was successfully tried using net exclosures [R. Muth, personal observation].

Chemical Treatment.—Traditional chemical treatments (e.g., rotenone) kill indiscriminantly and are not a viable control option. Red shiner has been targeted in two chemical-eradication projects in the Virgin River, Utah. Populations were substantially reduced after treatment but rapidly rebounded [L. Lentsch, personal observation].

Biological Control.—Red shiner are vulnerable to fish predation. Stocking Colorado squawfish (a piscivore) to supplement existing wild stocks could additionally facilitate reducing numbers of nonnative fishes, including red shiner.

Physicochemical Manipulations.—Correlative evidence has demonstrated that relative abundance of red shiner is negatively affected by high river discharges and associated lower water temperatures, suggesting that management of flow regimes to approximate natural hydrographs and periodically provide above-average magnitudes in spring and summer discharges would suppress abundance of red shiner. However, cause and effect relationships need to be determined.

Common Carp *Cyprinus carpio*

Native Distribution:

Temperate regions of Europe and Asia [Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

First introduced into the United States in the mid-late 1800's to serve as a food fish. Today, the species is found in warm waters throughout Canada and the United States. First introduced into Colorado in 1879 [Wiltzius 1981] and into Utah by 1881 [Sigler 1958]; introduction of common carp into the UCRB probably occurred shortly after its initial introduction into Colorado and Utah. Common carp is now common or abundant throughout the upper basin [Tyus et al. 1982; Nelson et al. 1995]. In the upper basin, common carp are locally abundant in sheltered habitats, particularly in impoundments, backwaters, shorelines, and along sand-silt, tamarisk-lined banks [Valdez 1990].

In a survey of CRB researchers, common carp ranked fourth on a list of 28 nonnative fish species considered to adversely impact native fishes of the CRB and the southwestern United States. Suspected impacts included predation on larvae of all native fishes, especially Colorado squawfish and razorback sucker, and competitive interactions with all native fishes, especially roundtail chub, Colorado squawfish, bluehead sucker, flannelmouth sucker and June sucker *Chasmistes liorus mictus*. Habitat alteration caused by activities of common carp was also listed as a possible impact [Hawkins and Nesler 1991].

General Habitat:

There is a Habitat Suitability Index Model for common carp [Edwards and Twomey 1982] that summarizes the species' habitat requirements and preferences.

Hardy, prolific fish capable of adapting to a wide variety of environmental conditions. Tolerant of low D.O., dramatic and sudden temperature changes, and high levels of pollution (even seek out effluent releases with high concentrations of nutrients and trace elements). Prefer warm lakes, reservoirs, and rivers with quiet, dark holes and an abundance of aquatic vegetation [Sigler 1958]. Found in habitats with various substrates and tolerant of clear or turbid water but generally not found in clear, cold water or rivers with high gradients.

Examples of Environmental Factors Affecting Distribution or Abundance:

- Tolerant of an incredibly wide range of physicochemical parameters. Tolerate a wide range of TDS and pH and high concentrations of nutrients.
- Factors negatively affecting common carp populations include disappearance of feeding and spawning areas, predation, pollution, siltation, parasitism, and disease [Sigler 1958].
- Avoid swift water, except during spawning, and depths > 33 m [Sigler 1958].

Temperature.—

- Optimum temperatures range 17-32°C, depending on acclimation temperature [Sigler 1958].
- Depending on acclimation temperature, CTM is between 31 and 36°C. The lower lethal body temperature is 0.7°C [Sigler 1958].
- Common carp are sluggish and don't feed at temperatures < 4.5°C [Sigler 1958].

Dissolved Oxygen.—

- One of the last species to survive in waters depleted of oxygen (< 0.1 mg/L) [Becker 1983].

Salinity.—

- Able to tolerate salinity concentrations of up to 17 ppt [Becker 1983].

General Behavior:

Benthic omnivore. Diet consists of insects, crustaceans, plant debris, algae, zooplankton, and fish [Sigler 1958].

Reproduction:

Maturation.—Males mature at 1-4 years of age, and females mature at 2-6 years [Carlander 1969]. Attain a maximum length of 107-122 cm. Average longevity is 9-15 years with a maximum of 47 years.

Spawning Requirements.—Over the range of this species, spawning occurs intermittently between March and August. In the Yampa River, 1976-1977, spawned mid May-mid August with peak spawning occurring early June-early July [Carlson et al. 1979]. Spawn over aquatic vegetation, tree roots, mud bottoms, and debris covering the bottom in rivers, lakes, marshes, swamps, ponds, and sheltered, vegetated areas of streams. Temperature is the primary stimulus for spawning. Spawning temperatures range 10-30°C with 18-23°C considered optimum [Mansueti and Hardy 1967].

Spawning Behavior and Biology.—Spawning often occurs during twilight hours [Brown 1971]. Eggs are deposited in batches of 500-600 over a 2-m area [Sublette et al. 1990]. Reported fecundity ranges 36,000 to over 2.2 million per kg body weight [Swee and McCrimmon 1966].

Eggs and Young.—Eggs are demersal, adhesive, and have a maximum diameter of 1.5-2.1 mm [Sigler 1958]. Incubation time is 3-5 d at 20°C and 5 d at 15°C [Mansueti and Hardy 1967]. Total length at hatching is 4-5 mm [Snyder 1981].

Examples of Interactions with Native Colorado River Basin Fishes:

- Because common carp was the most abundant nonnative fish in rivers of Dinosaur National Monument, Colorado and Utah, it was suspected of having a negative impact on native fishes by egg predation [Karp and Tyus 1990b].
- Common carp occupy the same habitats as the endangered fishes throughout the Yampa River, Colorado, during all seasons [Irving and Karp 1995].

■ Predation by nonnative fishes, including common carp, was concluded as the cause for loss of young razorback sucker in an isolated backwater on the shores of Lake Mohave, Arizona-Nevada [Marsh and Langhorst 1988].

■ Common carp were observed feeding in redds of razorback sucker in Lake Mohave soon after razorback sucker had spawned. However, eggs were not found in stomachs of common carp examined, and it was concluded that the impact, if any, of predation by common carp on razorback sucker eggs was insignificant given the large number of eggs available and the lack of eggs in common carp stomachs [Bozek et al. 1984].

Options for Control in the Upper Colorado River Basin:

Several chemical, physical, and biological measures have been tried to control or eradicate common carp [Carlander 1969; Becker 1983]. An attempt was made to force-feed common carp chemicals in the hope of finding a selective, species-specific toxicant. Of the 1,496 chemicals tested, only seven were acutely lethal [Loeb and Kelly 1963]. Other methods used in attempts to control or eradicate common carp include seining, barricades, fluctuating water levels, introducing species-specific parasites and diseases, electricity, chemicals, introducing predators, increasing commercial and recreational harvests, and prohibiting use of common carp as bait fish [Sigler 1958; Wydoski 1992]. Most recently, rotenone was mixed with food in an attempt to selectively eradicate common carp [Fajt and Grizzle 1993]. The ubiquitous distribution of common carp combined with their hardiness make efforts to eradicate or even control common carp ineffective, except in small, isolated lakes [Cross 1967].

Mechanical Removal.—Exploitation of the commercial and sport possibilities of common carp is the most promising solution for controlling the species [Sigler 1958; Becker 1983]. Taking this approach would be virtually impossible in the upper basin given the inaccessibility of much of the basin. Spawning aggregations could be targeted for electrofishing or netting.

Chemical Treatment.—Spawning aggregations could be targeted but would result in loss of native fishes.

Biological Control.—Options undetermined.

Physicochemical Manipulations.—Options undetermined.

Utah Chub *Gila atraria*

Native Distribution:

Bonneville Basin and the Snake River drainage above Shoshone Falls [Sigler and Miller 1963].

Distribution and Status in Upper Colorado River Basin:

Introduced into the CRB by 1933 [Sigler and Miller 1963]. In the UCRB, rare or incidental in the Duchesne, Dirty Devil, Price, and Yampa river drainages; abundant in Flaming Gorge Reservoir [Tyus et al. 1982].

In a survey of CRB researchers, Utah chub ranked eleventh (tied with plains minnow, sheepshead minnow *Cyprinodon variegatus*, plains killifish, rock bass *Ambloplites rupestris*, bluegill, and white crappie on a list of 28 nonnative fish species considered to adversely impact native fishes of the CRB and the southwestern United States [Hawkins and Nesler 1991].

General Habitat:

Found in a variety of habitats including lakes, reservoirs, ponds, sloughs, creeks, and irrigation ditches; generally not found in larger rivers [Sigler and Miller 1963]. Particularly successful in reservoirs with large littoral zone where the species is considered a nuisance by anglers and fishery biologists [Sigler and Miller 1963; Valdez 1993]. Young prefer littoral areas, and adults prefer pelagic zones. Tolerant of a wide range of biotic and abiotic factors but prefer slow, clear vegetated areas [Tyus et al. 1982].

Examples of Environmental Factors Affecting Distribution or Abundance:

- The Utah chub appears to be declining in its native range. Factors limiting its abundance in native habitats have not been determined, but water quality, competition, and predation are possible contributors [Valdez 1993].
- Thrive under a wide range of physicochemical conditions and able to sustain populations even under adverse conditions [Sigler and Sigler 1987]. Tolerant of swift or slow water but prefer little or no velocity. Generally found in clear water but tolerant of turbid water. Found associated with a variety of substrate types [Sigler and Miller 1963].

- Water of desert springs and spring-fed ditches inhabited by Utah chub often tastes soapy, strongly alkaline, or salty suggesting that the species can survive under a considerable range of chemical conditions [Sigler and Miller 1963].

- Typically found in lakes and reservoirs at elevations of 1,500-2,700 m.

- Typically found in upper 5 m of water but have been caught in gill nets at depths of 23 m in Bear Lake [Sigler and Miller 1963; Varley and Livesay 1976].

Temperature.—

- Collected from water with temperatures of 2-31°C; show no preference for cool or warm water [Sigler and Miller 1963].

Hydrogen Ion Concentration (pH).—

- Collected from water with pH of 5.0-9.6 [Neuhold 1955].

General Behavior:

A schooling forage fish that is an opportunistic omnivore. Diet consists mostly of zooplankton in fish \leq 180 mm TL. Larger fish eat algae, other vegetation, macroinvertebrates, and occasionally fish or fish eggs [John 1959; Graham 1961; Sigler and Miller 1963].

Reproduction:

Maturation.—Generally, males mature in 2-3 years, and females mature in 3-4 years [Sigler and Sigler 1987; Valdez 1993]. Reported maximum age is up to 11 years; maximum mean age is 5-8 years [Neuhold 1955; Sigler and Miller 1963]. Growth is most rapid during the first 3-4 years of life [Sigler and Sigler 1987]. Typically grow to 125-200 mm TL and 0.5 kg in weight; have been reported up to 580 mm TL and 1.5 kg in weight [Valdez 1993].

Spawning Requirements.—Typically spawn during late spring and summer in shallow (< 0.6 m deep), vegetated littoral zones [Sigler and Miller 1963; Varley and Livesay 1976]. In Utah Lake, Utah, spawning has been reported as early as April [Sigler and Miller 1963]. Spawning is initiated at water temperatures of 12-19°C [Graham 1961; Varley and Livesay 1976].

Spawning Behavior and Biology.—Reported fecundity ranges 10,000-84,000 eggs per female per year. Mean clutch size is 13,000-40,000 eggs per year depending on age of the female [Varley and Livesay 1976]. Males are golden in color during

breeding season and have traces of yellow or orange color on pectoral fins [Sigler and Miller 1963]. Spawning migrations have been reported in lake populations [Sigler and Sigler 1987].

Eggs and Young.—Eggs have a maximum diameter of 1.4-1.6 mm [Snyder 1981]. Incubation time is 6 d at 19°C and 9 d at 18°C [Sigler and Sigler 1987]. Total length at hatching is 4 mm [Snyder 1981].

Examples of Interactions with Native Colorado River Basin Fishes:

- None found.

Options for Control in the Upper Colorado River Basin:

Although the Utah chub is adaptable, fluctuating flows, high turbidity, lack of suitable lentic habitats, and predation or competition in rivers of the upper basin probably prevent or limit successful invasion of larger rivers. Accordingly, the species has little or no impact on the endangered or other native fishes. Probably, the only effective way to control large populations of Utah chub is a total kill [Sigler and Miller 1963].

Mechanical Removal.—Spawning congregations of adults and early life stages in littoral areas are vulnerable to mechanical removal.

Chemical Treatment.—The Utah chub has been a target species in two chemical eradication projects in Strawberry Reservoir. There is potential for complete chemical eradication in reservoirs or selective eradication during or soon after spawning.

Biological Control.—Introduce predators. In Flaming Gorge Reservoir, Utah chub populations have been greatly reduced by predation from lake trout *Salvelinus namaycush*.

Physicochemical Manipulations.—Lowering water levels in reservoirs to dry up spawning areas. Prolonged exposure to swift water or eliminating littoral vegetation would impact populations.

Leatherside Chub *Gila copei*

Native Distribution:

Bonneville and upper Snake River basins of Utah, Idaho, and Wyoming, and Wood River drainage of Idaho [Simpson and Wallace 1978].

Distribution and Status in Upper Colorado River Basin:

Rare in the Freemont, Price, and Strawberry rivers [Tyus et al. 1982]. Introductions in the lower Colorado River have been unsuccessful [Valdez 1993].

General Habitat:

Prefer cool, clear pool and riffle habitats over sand, silt, or boulder substrates in moderately flowing creeks [Sigler and Miller 1963; Valdez 1993].

Examples of Environmental Factors Affecting Distribution or Abundance:

■ Restricted to clear, cool small rivers with low turbidity and temperatures of 10-23°C. Typically found at depths < 0.3 m in moderate currents [Sigler and Sigler 1987].

General Behavior:

Omnivorous. Feed on drifting organisms, algae, and aquatic insects [Sigler and Sigler 1987].

Reproduction:

Maturation.—Attain a maximum length of 152 mm; mean is 90 mm. Typically live < 5 years [Carlander 1969; Sigler and Sigler 1987].

Spawning Requirements.—Spawn over gravel substrates during June through August at water temperatures of 17-20°C [Sigler and Sigler 1987].

Spawning Behavior and Biology.—Spawn in aggregations [Sigler and Sigler 1987].

Eggs and Young.—No information.

Examples of Interactions with Native Colorado River Basin Fishes:

■ None found.

Options for Control in the Upper Colorado River Basin:

Because of its restrictive habitat requirements, the leatherside chub is not a threat to native fishes of upper basin rivers.

Brassy Minnow *Hybognathus hankinsoni*

Native Distribution:

From the upper St. Lawrence River west to southern Alberta and south into Nebraska and eastern Colorado [Carlander 1969; Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

Reported in a few collections from the Colorado River near Grand Junction; very incidental [Tyus et al. 1982].

General Habitat:

Live in small, sluggish creeks of streams with sand, gravel, or mud substrates and aquatic vegetation. Also found in cool, acidic waters of bog streams or ponds [Scott and Crossman 1973; Lee et al. 1980; Becker 1983]. Rare in larger rivers or lakes [Becker 1983].

Examples of Environmental Factors Affecting Distribution or Abundance:

- Particularly vulnerable to fish predation [Becker 1983].
- Tolerant of moderate currents but prefer slow water. Generally found at depths of 0.1-1.5 m (depending on the season) and in clear to slightly turbid water over muddy substrates [Becker 1983].

Temperature.—

- Reported temperature limits ranged 0.0-28.9°C. Able to withstand sudden temperature changes of $\pm 17^{\circ}\text{C}$ [Becker 1983].

Dissolved Oxygen.—

- Tolerant of D.O. concentrations as low as 1.5 ppm [Becker 1983].

General Behavior:

A schooling fish that is an opportunistic omnivore. Known to participate in group feedings [Scott and Crossman 1973; Becker 1983].

Reproduction:

Maturation.—Typically become sexually mature in the second year of life; reports of females maturing at age 1 [Becker 1983]. Attain a maximum length of 71-102 mm; may live up to 3 years [Scott and Crossman 1973].

Spawning Requirements.—Spawn in spring at water temperatures of 16-27°C [Starrett 1951; Ableson 1973; Copes 1975; Becker 1983]. Spawn in quiet, vegetated habitats with silt bottom [Scott and Crossman 1973; Becker 1983].

Spawning Behavior and Biology.—Reported fecundity is 1,000-3,000 eggs per female. Eggs scattered among vegetation [Ableson 1973; Copes 1975]. Females will spawn for 7-10 d [Becker 1983].

Eggs and Young.—Eggs demersal, slightly adhesive [Scott and Crossman 1973; Copes 1975]. Total length at hatching is 4 mm [Snyder 1981].

Examples of Interactions with Native Colorado River Basin Fishes:

- None found.

Options for Control in the Upper Colorado River Basin:

Upper basin rivers do not provide optimum habitat for brassy minnow. Further expansion of this species in the upper basin appears unlikely; presently not a threat to the endangered or other native fishes.

Plains Minnow *Hybognathus placitus*

Native Distribution:

Throughout plains states, from Montana and North Dakota south to central Texas and east to southwestern Illinois and western Kentucky [Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

Collected from the San Juan River inflow to Lake Powell where its occurrence is rare or incidental [Tyus et al. 1982].

In a survey of CRB researchers, plains minnow ranked eleventh (tied with Utah chub, sheepshead minnow, plains killifish, rock bass, bluegill and white crappie on a list of 28 nonnative fish species considered to adversely impact

native fishes of the CRB and the southwestern United States. Listed specifically as a competitor with Rio Grande silvery minnow *Hybognathus amarus* [Hawkins and Nesler 1991].

General Habitat:

Typically found in open, shallow, slow-flowing channels, backwaters, or eddies of larger rivers [Cross 1967; Sublette et al. 1990]. Rarely found in small, intermittent streams or in muddy rivers [Cross 1967].

Examples of Environmental Factors Affecting Distribution or Abundance:

- Prefer slow to stagnant, shallow water with sandy substrate.
- Elimination of highly variable water levels and presence of unstable streambeds and fluctuating water temperatures caused by diversions and impoundments are reasons for the decline of prairie fishes, including the plains minnow, within their native ranges [Taylor and Miller 1990].

Temperature and Dissolved Oxygen.—

- When acclimated at 21°C, plains minnow preferred 30°C at D.O. concentrations of 5-9 mg/L; however, selected 17°C when D.O. dropped to 2 mg/L [Bryan et al. 1984].

General Behavior:

Schooling fish. Herbivorous, feeding on microscopic plant material [Cross 1967].

Reproduction:

Maturation.—Males and females mature in the first year of life [Cross 1967; Taylor and Miller 1990]. Maximum length typically ≤ 100 mm; live up to 2 years [Taylor and Miller 1990].

Spawning Requirements.—Spawn in quiet water along sandbars or in backwaters. Spawning occurs during late April through August. Spawning commences at high or receding flows [Cross 1967; Taylor and Miller 1990]. Peak spawning appears to be positively correlated with day length and water temperature [Sublette et al. 1990].

Spawning Behavior and Biology.—Communal, intermittent spawner [Cross 1967; Sublette et al. 1990; Taylor and Miller 1990].

Eggs and Young.—Eggs slightly adhesive and semi-buoyant [Sublette et al. 1990].

Examples of Interactions with Native Colorado River Basin Fishes:

- None found.

Options for Control in the Upper Colorado River Basin:

Occurrence of plains minnow in the upper basin is so rare that no control measures are needed.

Sand Shiner *Notropis stramineus*

Native Distribution:

Gulf Slope drainages in Texas northwest of the Mississippi River (excluding Louisiana and Arkansas) into the upper Mississippi Valley (including the Missouri River Basin), lower Red River of North drainage (in Canada), lower Great Lakes east into the upper Ohio River Basin, and south into the Tennessee River drainage [Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

Common or abundant in middle and lower portions of the Yampa, Green, and Colorado rivers. Found in low-velocity nursery habitats of native fishes (all life stages of sand shiner occur in these habitats) [Tyus et al. 1982; Haines and Tyus 1990; Nelson et al. 1995]. In the lower 80 km of the mainstem Colorado River (from Potash, Utah, to its confluence with the Green River), where sand is the predominant substrate, sand shiner was the most dominant species; conversely, sand shiner constituted < 3% of all fish collected in the lower 80 km of the Green River, where silt is the primary substrate [Valdez 1990].

In a survey of CRB researchers, sand shiner ranked sixth on a list of 28 nonnative fish species considered to adversely impact native fishes of the CRB and the southwestern United States. Suspected impacts included predation on larvae of native fishes, especially Colorado squawfish and razorback sucker, and competitive interactions with young of native fishes, especially Colorado squawfish [Hawkins and Nesler 1991].

General Habitat:

Primarily a riverine species but occurs in impoundments. Prefer medium- to large-sized streams and rivers having permanent flow, seasonally warm temperatures, moderate to high gradient, moderate to high water velocities, and clear to moderately clear water. Typically found in slow-flowing shallow pools with clean sand or gravel substrates and little or no aquatic vegetation. May be uncommon or absent

in sluggish, silty, turbid streams [Beckman 1952; Summerfelt and Minckley 1969; Scott and Crossman 1973; Tanyolac 1973; Eddy and Underhill 1974; Cross and Collins 1975; Smith 1979; Trautman 1981; Woodling 1981; Becker 1983; Harlan et al. 1987; Robison and Buchanan 1988; Sublette et al. 1990].

Examples of Environmental Factors Affecting Distribution or Abundance:

- Tolerant of variable flow conditions [Summerfelt and Minckley 1969; Trautman 1981; Sublette et al. 1990]. Occur at various water depths in rivers; found at depths of 34 m in Lake Erie [Becker 1983].
- Abundance decreases in absence of sand or gravel substrates. In Ohio, abundance of sand shiner has decreased from historic levels due to the species inability to adjust to high erosion and siltation [Trautman 1981].
- Abundance found to vary inversely with abundance of red shiner; attributed to species-specific differences in habitat preferences [Summerfelt and Minckley 1969].
- In the Des Moines River, Iowa, poor recruitment might have been related to high population densities and lower amounts of available space (implies self-regulation of population size) [Starett 1951].

Temperature.—

- Reported optimal temperatures ranged 24-32°C [Summerfelt and Minckley 1969].
- Fish acclimated at 15°C had a mean CTM of 33.10°C [Kowalski 1978]. However, spawning has been reported at temperatures of 37°C [Summerfelt and Minckley 1969].

Flow and Temperature.—

- For fish in the Yampa River, 1980-1984, earlier initiation of spawning, longer spawning season, and higher CPUE of age-0 individuals were associated with low peak discharge, low to moderate daily mean and total discharges, and moderate to high numbers of cumulative degree-days. Conversely, later initiation of spawning, shorter spawning season, and lower CPUE were associated with high peak discharge, moderate to high daily mean and total discharges, and low to moderate numbers of cumulative degree-days [Muth and Nesler 1993].

■ For fish in the Colorado (Colorado and Utah) and Gunnison rivers, moderate to significant inverse relationships were noted between magnitude of discharge and abundance of sand shiner [McAda and Kaeding 1989; Osmundson and Kaeding 1989a, 1991; Valdez 1990].

Dissolved Oxygen.—

■ Tolerant of D.O. concentrations as low as 1.4 ppm [Becker 1983].

Hydrogen Ion Concentration (pH).—

■ Avoid acidic or highly alkaline conditions; tolerant of pH 7.0-9.6 [Sublette et al. 1990].

General Behavior:

Live in schools in midwater or near the bottom. Generalized food habits (omnivorous). Feed on or near the bottom. Diet consists primarily of aquatic or terrestrial insects, crustaceans, algae, plant material, and detritus [Carlander 1969; Scott and Crossman 1973; Eddy and Underhill 1974; Pflieger 1975; Simpson and Wallace 1978; Jacobi and Jacobi 1982; Harlan et al. 1987; Robison and Buchanan 1988].

Reproduction:

Maturation.—Typically mature as yearlings (age 1); ≥ 40 mm total length. Attain a maximum length of 80-102 mm [Carlander 1969; Baxter and Simon 1970; Pflieger 1975; Smith 1979; Phillips et al. 1982; Harlan et al. 1987]. In Kansas, reported maximum life span was 3 years [Tanyolac 1973]. Generally, there is a sharp decline in abundance of age-2 fish after their second spawning [Starett 1951; Summerfelt and Minckley 1969].

Spawning Requirements.—Little is known. Spawn in shallow areas of rivers and impoundments. Eggs are probably scattered over clean sand or gravel [Carlander 1969; Baxter and Simon 1970; Scott and Crossman 1973; Miller and Robison 1973; Robison and Buchanan 1988;]. In Wisconsin, spawn late May-mid August [Becker 1983]. In Iowa, spawn June-early September [Carlander 1969; Scott and Crossman 1973]. In Kansas, spawn April-August with peak spawning occurring in late July and August; water temperatures ranged 21-37°C [Summerfelt and Minckley 1969; Cross and Collins 1975]. In Oklahoma, spawn late spring-summer [Miller and Robison 1973; Robison and Buchanan 1988]. In the Yampa River, 1976-1977, spawned June-mid September with peak spawning occurring mid June-August [Carlson et al. 1979]. Spawning in summer at high water temperatures might be an adaptation to

enhance survival of young in Great Plains rivers, where spring flows are characterized by drastic fluctuations [Summerfelt and Minckley 1969].

Spawning Behavior and Biology.—Little is known; possibly a fractional spawner [Muth and Nesler 1993]. Reported fecundity (number of eggs per female) at selected ages was: age 1 - 250, age 2 - 1,110, and age 3 - 1,800 [Carlander 1969; Scott and Crossman 1973]. Average number of mature eggs per female is 650-747 [Robison and Buchanan 1988].

Eggs and Young.—Eggs have a maximum diameter of 0.65-0.9 mm [Summerfelt and Minckley 1969]. Total length at hatching is 3-4 mm [Snyder 1981]. Estimated daily growth of larvae and early juveniles is 0.2-0.3 mm [Carlson et al. 1979]. Estimated total length at end of first year is ≤ 40 mm [Carlander 1969].

Examples of Interactions with Native Colorado River Basin Fishes:

- Diet overlap between sand shiner and young Colorado squawfish in backwaters of the Green River, Colorado and Utah, was below the level of biological importance [Muth and Snyder 1995].
- In the Colorado and Green rivers, Colorado and Utah, habitats of age-0 Colorado squawfish and sand shiner overlapped [McAda and Kaeding 1989b].

Options for Control in the Upper Colorado River Basin:

Although not as ubiquitous or abundant as red shiner, sand shiner are locally common or abundant and sympatric with native fishes in nursery habitats.

Mechanical Removal.—Partial, temporary removal might be achieved by periodic seining of selected, localized low-velocity habitats.

Chemical Treatment.—Traditional chemical treatments (e.g. rotenone) kill indiscriminantly and are not a viable control option.

Biological Control.—Sand shiner are vulnerable to fish predation. Stocking Colorado squawfish (a piscivore) to supplement existing wild stocks could additionally facilitate reducing numbers of nonnative fishes, including sand shiner.

Physicochemical Manipulations.—Correlative evidence has demonstrated that relative abundance of sand shiner is negatively affected by high river discharges and associated lower water temperatures, suggesting that management of flow

regimes to approximate natural hydrographs and periodically provide above-average magnitudes in spring and summer discharges would suppress abundance of sand shiner. However, cause and effect relationships need to be determined.

Fathead Minnow *Pimephales promelas*

Native Distribution:

Central North America, from the Rocky to the Appalachian mountains and from southern Canada to northeastern Mexico; from Chihuahua, Mexico, north to the Great Slave Lake drainage, east to New Brunswick, and west to Alberta [Cross 1967; Scott and Crossman 1973; Lee et al. 1980; Sublette et al. 1990].

Distribution and Status in Upper Colorado River Basin:

Widely introduced throughout the United States including the CRB. Common or abundant in middle and lower sections of larger rivers of the UCRB and widespread and established in the Lower Colorado River Basin [Minckley 1973; Tyus et al. 1982; Sublette et al. 1990; Nelson et al. 1995]. Found in low-velocity nursery habitats of native fishes (all life stages of fathead minnow occur in these habitats) [Tyus et al. 1982; Haines and Tyus 1990].

In a survey of CRB researchers, fathead minnow ranked fifth (tied with green sunfish) on a list of 28 nonnative fish species considered to adversely impact native fishes of the CRB and the southwestern United States. Suspected impacts included predation on larvae of native fishes, especially Colorado squawfish and razorback sucker, and competitive interactions with young of native fishes, especially Colorado squawfish [Hawkins and Nesler 1991].

General Habitat:

Found in a wide range of habitats in ponds, lakes, reservoirs, streams, and rivers. Associated with a variety of substrate types, from silt to boulders, but most commonly found in habitats with finer substrates. Prefer areas with vegetation. Extremely tolerant of waters with high temperature, turbidity, and salinity and low dissolved oxygen; tolerant of a wide pH range and pollution [Carlander 1969; Minckley 1973; Scott and Crossman 1973; Pflieger 1975; Lee et al. 1980; Woodling 1981; Becker 1983; Sublette et al. 1990].

Examples of Environmental Factors Affecting Distribution or Abundance:

- Exhibits the greatest ecological diversity of any North American cyprinid [Becker 1983].
- Considered a pioneer species, one of the first species to invade intermittent streams. Often one of the last species remaining in small pools of intermittent streams during dry conditions; flourish where few other fishes survive [Cross 1967].
- Prefer low velocities (< 15 cm/s) and found in a variety of water depths [Becker 1983; Sublette et al. 1990].
- Appear to be intolerant of competition with other fishes.

Temperature.—

- Reported thermal tolerances ranged 0-35°C; optimal temperatures were 22-23°C [Scott and Crossman 1973; Becker 1983].
- Temperature preferences ranged 19.8-28.9°C at various acclimation temperatures; mortality occurred at 30°C [Cherry et al. 1975].

Flow and Temperature.—

- For fish in the Yampa River, 1980-1984, earlier initiation of spawning, longer spawning season, and higher CPUE of age-0 individuals were associated with low peak discharge, low to moderate daily mean and total discharges, and moderate to high numbers of cumulative degree-days. Conversely, later initiation of spawning, shorter spawning season, and lower CPUE were associated with high peak discharge, moderate to high daily mean and total discharges, and low to moderate numbers of cumulative degree-days [Muth and Nesler 1993].
- For fish in the Colorado (Colorado and Utah) and Gunnison rivers, moderate to significant inverse relationships were noted between magnitude of discharge and abundance of fathead minnow [McAda and Kaeding 1989a; Osmundson and Kaeding 1989, 1991; Valdez 1990].
- In Green River, Utah, 1979-1988, most abundant in backwaters > 15 cm deep and having cooler water temperatures ($< 22.5^{\circ}\text{C}$). CPUE was unaffected by different summer flows [Haines and Tyus 1990].

Dissolved Oxygen.—

- Able to utilize gas bubbles beneath ice or in muskrat holes to withstand D.O. concentrations as low as 0.3 ppm [Klinger et al. 1982].

Hydrogen Ion Concentration (pH).—

- Tolerant of pH 5.5-9.8 [Matuszek et al. 1990].

Salinity.—

- Have been found in waters with salinity concentrations > 10,000 ppm, but in laboratory experiments, exposure to concentrations of 8,200 ppm for 48 h was lethal [Sublette et al. 1990].

Total Dissolved Solids (TDS).—

- Have been found in waters with TDS of 385-7,036 mg/L, but were absent in lake with TDS concentrations > 23,000 mg/L; TDS levels of about 15,000 mg/L were considered lethal [Matuszek et al. 1990; Held and Peterka 1974].

General Behavior:

Live in schools in midwater or near the bottom. Diet consists mostly of organic detritus, algae, and other plant material but also consume aquatic insects and zooplankton [Minckley 1973; Scott and Crossman 1973; Pflieger 1975; Woodling 1981; McAda and Tyus 1984; Sublette et al. 1990; Ruppert et al. 1993]. Piscivory on larvae of the Lost River sucker *Deltistes luxatus* and the shortnose sucker *Chasmistes brevirostris* was documented in laboratory experiments [Dunsmoor 1993].

Reproduction:

Maturation.—Growth is rapid. Some individuals may mature and spawn during their first summer or fall of life, but most do not spawn until their second summer (age 1); > 40 mm TL. Short lived; life span is typically 2 years. Attain a maximum length of about 75-89 mm, commonly 50-75 mm [Sigler and Miller 1963; Carlander 1969; Minckley 1973; Scott and Crossman 1973; Pflieger 1975].

Spawning Requirements.—Prolonged spawning season. Spawn from May well into summer or early fall. Apparently, spawning begins when water temperatures reach about 16-18°C; reported range up to 19°C [Sigler and Miller 1963; Scott and Crossman 1973; Eddy and Underhill 1974; Pflieger 1975; Smith 1979; Sublette et al. 1990; Woodling 1981]. In the Yampa River, 1976-1977, spawned early May-early September with peak spawning occurring late

May-mid August [Carlson et al. 1979]. Some uncertainty as to whether temperature, photoperiod, or both initiates spawning [Becker 1983].

Spawning Behavior and Biology.—General spawning habits are well known. Eggs are spawned on the undersurface of submerged or floating objects (may create suitable spawning sites under rocks in the absence of such objects). Male guards and tends the "nest" and may spawn with several females, producing a large nest possibly containing several thousand eggs; maybe up to 12,000 eggs in a single nest [Markus 1934; Carlander 1969; Minckley 1973; Scott and Crossman 1973; Pflieger 1975; Woodling 1981; Gale and Buynak 1982; Sublette et al. 1990]. Fecundity and spawning frequency was studied under controlled conditions, and it was determined that the species is a fractional spawner [Gale and Buynak 1982]. In that study, 16-26 clutches of eggs were produced by each spawning pair. Number of eggs spawned per female ranged 6,803-10,164 (mean 8,604). Nine to 1,136 eggs were spawned per clutch (mean ranged 391-480). Intervals between spawning of each clutch ranged 2-16 d. Spawning typically began before dawn and ended by mid morning. No postspawning mortality was noted; however, in another study [Markus 1934], about 85% of the adults died after spawning.

Eggs and Young.—Eggs are demersal, adhesive, and have a maximum diameter of 1.15-1.3 mm (maybe up to 1.6 mm). Incubation time is 4-6 d at water temperatures of 23-30°C; 5 d at 25°C [Markus 1934; Carlander 1969; Scott and Crossman 1973; Sublette et al. 1990]. Total length at hatching is 4 mm [Snyder 1981]. Estimated daily growth of larvae and early juveniles is 0.2-0.3 mm [Carlson et al. 1979]. Total length at end of first year is \leq 50 mm [Carlander 1969].

Examples of Interactions with Native Colorado River Basin Fishes:

- Diet overlap between fathead minnow and young Colorado squawfish in backwaters of the Green River, Colorado and Utah, was below the level of biological importance. Larval fathead minnow were identified in guts of some age-0 Colorado squawfish [Muth and Snyder 1995].
- In the Green River, Utah, 1980, high habitat-use overlap (index value of 0.80) between age-0 Colorado squawfish and fathead minnow. No significant dietary overlap between age-0 Colorado squawfish and fathead minnow [McAda and Tyus 1984].
- In the Colorado and Green rivers, Colorado and Utah, habitats of age-0 Colorado squawfish and fathead minnow overlapped [McAda and Kaeding 1989b].

■ Observations on behavioral interactions under laboratory conditions suggested that in shared habitats, fathead minnow may adversely affect growth and survival of age-0 Colorado squawfish [Karp and Tyus 1990a].

■ Experimental evidence of competition for food between larvae of Colorado squawfish and fathead minnow under laboratory conditions [Beyers et al. 1994].

Options for Control in the Upper Colorado River Basin:

Controlling or limiting fathead minnow will be difficult because of its high abundance, widespread distribution, high adaptability, high reproductive potential, and ability to rapidly re-colonize.

Mechanical Removal.—Partial, temporary removal might be achieved by periodic seining of selected low-velocity habitats.

Chemical Treatment.—Traditional chemical treatments (e.g., rotenone) kill indiscriminantly and are not a viable control option.

Biological Control.—Fathead minnow are vulnerable to fish predation. Stocking Colorado squawfish (a piscivore) to supplement existing wild stocks could additionally facilitate reducing numbers of nonnative fishes, including fathead minnow.

Physicochemical Manipulations.—Correlative evidence has demonstrated that relative abundance of fathead minnow is negatively affected by high river discharges and associated lower water temperatures, suggesting that management of flow regimes to approximate natural hydrographs and periodically provide above-average magnitudes in spring and summer discharges would suppress abundance of fathead minnow. However, cause and effect relationships need to be determined.

Longnose Dace *Rhinichthys cataractae*

Native Distribution:

One of the widest distributions of any North American cyprinid [Bartnik 1972]. Widely distributed throughout central North America, from British Columbia to New Foundland south to Pennsylvania and Oregon. Distribution extends south through the Rocky Mountains to northern Mexico

and east through the Appalachian Mountains to South Carolina [Carlander 1969; Lee et al. 1980]. Native to the Bonneville Basin.

Distribution and Status in Upper Colorado River Basin:

Introduced into the upper basin as a forage fish. Collected from the Green River above Flaming Gorge Dam and from the Strawberry River, a tributary of the Duchesne River; occurrence is rare or incidental [Tyus et al. 1982].

General Habitat:

There is a Habitat Suitability Index Model for longnose dace [Edwards et al. 1983] that summarizes the species' habitat requirements and preferences.

Live in swift and occasionally turbulent water [Becker 1983; Sigler and Sigler 1987]. Prefer cooler water (11-21°C) with gravel, rubble, or boulder substrates and overhead cover [Becker 1983; Sigler and Sigler 1987].

Examples of Environmental Factors Affecting Distribution or Abundance:

- Adults are mostly limited to swift, clear streams with coarse substrates; also found in lakes [Sigler and Miller 1963; Bartnik 1970; Becker 1983]. Young are restricted to areas of shallow water and moderate current [Woodling 1985].
- Usually found in streams with gradients of 1.9-18.2 m/km and velocities exceeding 0.4 m/s (up to 1.8 m/s). Rarely inhabit water > 1.0 m deep; typically found in water < 0.3 m deep [Sigler and Miller 1963; Becker 1983].
- Able to withstand rapid changes in environmental conditions [Becker 1983].

Temperature.—

- Optimum water temperatures range 12.8-21°C with a CTM of 27.8°C [Becker 1983].

Dissolved Oxygen.—

- Can endure high turbidity and low D.O. (0.3 ppm) for short periods of time [Becker 1983].

General Behavior:

A benthic dweller. Primarily, opportunistic, benthic insectivore; also consume algae and fish eggs [Becker 1983; Sigler and Sigler 1987].

Reproduction:

Maturation.—Typically mature by age 2 [Sigler and Sigler 1987]. May attain a maximum length of 127 mm; typically do not grow over 90 mm TL. Maximum longevity is 5 years [Becker 1983; Sigler and Sigler 1987; Valdez 1993].

Spawning Requirements.—Spawn in riffles of streams and along shorelines of lakes. Spawning may start as early as April and end as late as July [Bartnik 1972; Gee and Machniak 1972; Becker 1983]. In Utah, spawning occurs at water temperatures of 11-19°C, with an optimum spawning temperature of 17.2°C [Becker 1983; Valdez 1993].

Spawning Behavior and Biology.—Deposit eggs over gravel [Bartnik 1970]; may deposit eggs in nests of other cyprinids [Cooper 1980]. Spawning territory is established and is defended by one parent [Sigler and Sigler 1987]. Reported fecundity is 180-1,200 eggs per female [Becker 1983].

Eggs and Young.—Eggs are demersal, adhesive, and have a maximum diameter of 2.1-2.7 mm [Fuiman and Loos 1977]. Incubation time is 3-4 d at 18-24°C [Cooper 1980]; 7-10 d at 15°C [Sigler and Sigler 1987]. Total length at hatching is 5-6 mm [Cooper 1980; Snyder 1981].

Examples of Interactions with Native Colorado River Basin Fishes:

■ Within its native range, the longnose dace is known to hybridize with the speckled dace [Scott and Crossman 1973].

Options for Control in the Upper Colorado River Basin:

Limited to swift, cool streams. Not a threat to the endangered fishes, no control measures are needed.

Redside Shiner *Richardsonius balteatus*

Native Distribution:

Mostly west of the Rocky Mountains from the Nass River, British Columbia, south through Washington, Oregon, and the Columbia River drainage. Also in the Harney Basin, Oregon, and Bonneville Basin, Idaho, Wyoming, Utah, and Nevada.

Native east of the continental divide only in British Columbia and Alberta in the Peace River system [Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

In the UCRB, rare or incidental to common or abundant in the Yampa River and upper portion of the Green, Duchesne, and Dirty Devil rivers (rare or incidental in reaches occupied by young of endangered fishes) [Tyus et al. 1982]. Established in upper portions of the Lower Colorado River Basin [Minckley 1973].

In a survey of CRB researchers, redbase shiner ranked 10th (tied with yellow bullhead and smallmouth bass on a list of 28 nonnative fish species considered to adversely impact native fishes of the CRB and the southwestern United States. Suspected impacts included predation on larvae of native fishes and competitive interactions with young of native fishes, especially Colorado squawfish [Hawkins and Nesler 1991].

General Habitat:

Occupy a variety of habitats under various environmental conditions. Found in creeks, rivers with low to moderate water velocities, ponds, lakes, canals, sloughs, and warm springs. In streams, may occur in slow to swift, clear to turbid water and over rubble, gravel, sand, clay, or mud substrates. Frequently found associated with vegetation. Prefer cool water [Sigler and Miller 1963; Brown 1971; Scott and Crossman 1973; Simpson and Wallace 1978; Wydoski and Whitney 1979; Woodling 1981; Tyus et al. 1982; Sigler and Sigler 1987].

Examples of Environmental Factors Affecting Distribution or Abundance:

Temperature.—

- Prefer cool water, typically with summer water temperatures ranging 16-19°C (maximum range 13-21°C). Calculated upper lethal water temperature was 25°C when fish were acclimated at 8.9-11.1°C; 27°C when acclimated at 14°C [Sigler and Miller 1963; Brown 1971; Scott and Crossman 1973; Simpson and Wallace 1978; Wydoski and Whitney 1979; Woodling 1981; Tyus et al. 1982; Sigler and Sigler 1987].

Flow and Temperature.—

- For fish in the Yampa River, 1980-1984, earlier initiation of spawning, shorter spawning season, and higher CPUE of age-0 individuals were associated with low peak discharge, low to moderate daily mean and

total discharges, and moderate to high numbers of cumulative degree-days. Conversely, later initiation of spawning, longer spawning season, and lower CPUE were associated with high peak discharge, moderate to high daily mean and total discharges, and low to moderate numbers of cumulative degree-days. Associations between length of spawning season for redbreasted sunfish and discharge and cumulative degree-days were opposite of those exhibited by redear sunfish, sand shiner and fathead minnow; difference probably due to redbreasted sunfish's preference for cooler water [Muth and Nesler 1993].

General Behavior:

Live in schools, tend to stay near vegetated areas. In lakes, exhibit daily and seasonal movement patterns. In streams, move inshore in spring and remain there until mid-late summer; subsequently, move to deeper, cooler water. Omnivorous, consume primarily aquatic or terrestrial insects, snails, crustaceans, and fish eggs and larvae. Cannibalistic on own eggs and larvae; may be one of the most important factors limiting survival of their eggs and larvae [La Rivers 1962; Sigler and Miller 1963; Carlander 1969; Baxter and Simon 1970; Brown 1971; Scott and Crossman 1973; Minckley 1973; Simpson and Wallace 1978; Wydoski and Whitney 1979; Woodling 1981; Sigler and Sigler 1987].

Reproduction:

Maturation.—Mature at age 2 or age 3; ≥ 60 mm TL. Attain a maximum length of 178 mm (typically less than 125 mm). Relatively short lived; maximum life span is 5 years [Sigler and Miller 1963; Carlander 1969; Brown 1971; Scott and Crossman 1973; Simpson and Wallace 1978; Wydoski and Whitney 1979].

Spawning Requirements.—In streams, spawn in areas < 15 cm deep (maybe riffles or upwellings) with gravel or rocky substrates. In lakes, spawn along shoreline. Spawning area often associated with submerged vegetation. Spawning begins when water temperatures reach 10–14°C. Reported range of spawning season was May–August; typically June and July [La Rivers 1962; Sigler and Miller 1963; Carlander 1969; Baxter and Simon 1970; Brown 1971; Scott and Crossman 1973; Minckley 1973; Simpson and Wallace 1978; Wydoski and Whitney 1979; Woodling 1981; Sigler and Sigler 1987]. In the Yampa River, 1976–1977, spawned late May–August with peak spawning occurring early June–mid August [Carlson et al. 1979].

Spawning Behavior and Biology.—During spawning, fish gather in groups of about 30–50 individuals; actual spawning takes place in smaller groups of about six individuals [Weisel and Newman 1951; La Rivers 1962; Breder and Rosen 1964; Scott and Crossman

1973]. No territoriality or courting behavior has been noted. Spawn during daylight and darkness. Eggs are broadcasted over the substrate or over vegetation in lots of 10-20 each per female (eggs are expelled at irregular intervals). Spawning may continue for 3-7 d. Individuals may spawn several times in a season. Reported fecundity ranged 829-3,602 eggs per female. Apparently, high mortality in adult fish occurs after spawning [Carlander 1969; Brown 1971; Scott and Crossman 1973; Minckley 1973; Simpson and Wallace 1978; Wydoski and Whitney 1979; Sigler and Sigler 1987].

Eggs and Young.—Eggs are demersal, adhesive, and have a maximum diameter of 1.9-2.2 mm. Incubation time is 3-7 d at water temperatures of 20-21°C [Weisel and Newman 1951; La Rivers 1962; Sigler and Miller 1963; Carlander 1969; Baxter and Simon 1970; Brown 1971; Scott and Crossman 1973; Minckley 1973; Simpson and Wallace 1978; Sigler and Sigler 1987]. Total length at hatching is about 6 mm [Snyder 1981]. Estimated daily growth of larvae and early juveniles is 0.2-0.3 mm [Carlson et al. 1979]. Total length at end of first year is \leq 50 mm [Carlander 1969].

Examples of Interactions with Native Colorado River Basin Fishes:

■ Adult Colorado squawfish ate redbase shiner in the Yampa River as evidenced by regurgitation by captured fish [Tom Nesler, CDOW, personal communication].

Options for Control in the Upper Colorado River Basin:

Redside shiner is rare or incidental in reaches occupied by young of endangered fishes and probably has minimal, if any, negative effects on these fishes. However, it is common or abundant in upper portions of the Yampa, Green, Duchesne, and Dirty Devil rivers and may impact young of other native fishes.

Mechanical Removal.—Partial, temporary removal might be achieved by periodic seining of selected low-velocity habitats.

Chemical Treatment.—Probably not a viable control option.

Biological Control.—Redside shiner are vulnerable to fish predation. Stocking Colorado squawfish (a piscivore) to supplement existing wild stocks could additionally facilitate reducing numbers of nonnative fishes, including redbase shiner.

Physicochemical Manipulations.—Correlative evidence has demonstrated that relative abundance of redbase shiner is negatively affected by high river discharges and associated lower water temperatures, suggesting that management of flow

regimes to approximate natural hydrographs and periodically provide above-average magnitudes in spring and summer discharges would suppress abundance of redbside shiner. However, cause and effect relationships need to be determined.

Creek Chub *Semotilus atromaculatus*

Native Distribution:

Throughout eastern North America, from Manitoba south to New Mexico and east to the Atlantic Coast [Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

Mostly rare or incidental with a very spotty distribution. Considered common in the Yampa and Green rivers near their confluence [Tyus et al. 1982].

General Habitat:

There is a Habitat Suitability Index Model for creek chub [McMahon 1982] that summarizes the species' habitat requirements and preferences.

Considered one of the most abundant minnows in eastern North America [Scott and Crossman 1973]. Common in small streams, creeks, brooks, medium-sized streams, and occasionally lakes [Moshenko and Gee 1973; Becker 1983]. Optimum habitats are small, clear, cool streams with moderate to high gradients, gravel substrate, and well-defined riffles and pools with abundant cover and food [Hubert and Rahel 1989].

Examples of Environmental Factors Affecting Distribution or Abundance:

- Tolerate a wide range of species assemblages under varying environmental conditions [Sublette et al. 1990].
- Prefer slower water but can tolerate swift water [Moshenko and Gee 1973].
- Young prefer shallow to moderately deep water (< 50 cm), whereas adults prefer deeper water [Moshenko and Gee 1973].
- Prefer clear to slightly turbid water [Becker 1983]; however, in laboratory tests, creek chub tended to concentrate in turbid water [Gradell 1982]. Turbidity may function to physically or visually isolate creek chub from predators. Abundance of creek chub can be high in turbid

water when other factors are not limiting or in clear water where other forms of cover provide adequate concealment from predators [Gradell 1982].

■ Found in habitats with various substrates but prefer gravel, rubble, or sand [Becker 1983].

Temperature.—

■ In laboratory tests, creek chub selected 26.4°C. Depending on acclimation temperature, reported CTM ranged 25-33°C and critical thermal minimum ranged 0.7-1.7°C [Carlander 1969; Stauffer et al. 1984].

General Behavior:

A schooling fish. Opportunistic omnivore, taking a variety of terrestrial insects and aquatic invertebrates; become more piscivorous with age [Moshenko and Gee 1973; Scott and Crossman 1973].

Reproduction:

Maturation.—Males mature in the third year of life and females in the second (females may mature at age 1) [Carlander 1969; Moshenko and Gee 1973]. Typical longevity is 5-6 years; maximum reported age is 7 years. Adults rarely exceed 300 mm TL [Scott and Crossman 1973; Becker 1983].

Spawning Requirements.—Spring-early summer spawner. Spawn at temperatures of 13-18°C; nesting stops at temperatures below 11°C [Moshenko and Gee 1973; Scott and Crossman 1973; Becker 1983]. Spawning occurs in runs or lower end of pools of small streams with gravel substrate.

Spawning Behavior and Biology.—Males create elongated depressions ("nest") [Moshenko and Gee 1973; Scott and Crossman 1973; Loos et al. 1979; Becker 1983]. Females spawn several times over many days [Scott and Crossman 1973]; 25-50 eggs deposited each time [Sublette et al. 1990]. Fecundity estimates range 1,000-7,000 eggs per female, depending on female size and weight [Carlander 1969; Moshenko and Gee 1973].

Eggs and Young.—Eggs are demersal, nonadhesive, and have a maximum diameter of 2.0-2.2 mm [Loos et al. 1979]. Incubation time is 10 d at 13°C and 6 d at 18°C [Washburn 1948; Buynak and Mohr 1979]. Total length at hatching is 6-7 mm [Snyder 1981].

Examples of Interactions with Native Colorado River Basin Fishes:

■ None found.

Options for Control in the Upper Colorado River Basin:

Further expansion of this species in the upper basin appears unlikely; not a threat to the endangered or other native fishes.

Catostomidae-Suckers

Utah Sucker *Catostomus ardens*

Native Distribution:

Bonneville Basin of Utah, Wyoming, Idaho, and Nevada, and the Snake River drainage above Shoshone Falls in Idaho and Wyoming [Sigler and Miller 1963; Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

The Utah sucker is presently found in all major drainages of Utah and was introduced into the UCRB by bait-bucket transfer. In the upper basin, the species is considered rare or incidental, occurring primarily in the Strawberry, Duchesne, and Dirty Devil drainages of Utah [Tyus et al. 1982].

General Habitat:

An adaptable species found in reservoirs, lakes, and streams. It is a bottom dweller that is tolerant of a wide range of temperatures, substrates, and turbidities [Sigler and Sigler 1987]. Typically found in reservoirs or quiet waters in rivers with cobble or gravel substrates and emergent vegetation [Valdez 1993].

Examples of Environmental Factors Affecting Distribution or Abundance:

- Tolerate a wide range of physicochemical conditions. Specific limiting factors are unknown.

General Behavior:

Benthic, omnivorous feeder [Sigler and Miller 1963].

Reproduction:

Maturation.—Typically mature at age 2 or age 3. Average longevity is 10-12 years [Sigler and Sigler 1987]. Adults are typically 400-600 mm long and weigh 0.8-2.0 kg.

Spawning Requirements.—Spring spawner, usually late May-mid June; spawning begins as water temperatures approach 15°C [Sigler and Sigler 1987]. Spawn in tributary streams, inlets, or rocky shoals of lakes over sand or gravel in water < 60 m deep [Snyder and Muth 1990].

Spawning Behavior and Biology.—Spawning occurs over a 30-d period. Observed in spawning aggregations of 400-500 individuals [Snyder and Muth 1990]. Substrate is "stirred" by males to partially bury eggs. Reported fecundity of four females (44-56 mm TL) averaged 38,525 eggs per female [Andreasen 1975].

Eggs and Young.—Eggs are demersal, initially adhesive, and have a maximum diameter of 2.9-3.2 mm. Larvae hatch in 8-9 d at 17°C and swim-up 7-8 d after hatching. Total length at hatching is 8-11 mm [Snyder and Muth 1990].

Examples of Interactions with Native Colorado River Basin Fishes:

- None found.

Options for Control in the Upper Colorado River Basin:

The Utah sucker was a subject of chemical eradication projects in Strawberry Reservoir, where the species competes with and displaces trout. The most recent effort to eliminate this fish from Strawberry Reservoir in 1990 apparently reduced populations to targeted levels.

Lack of lentic habitats combined with high turbidity, erratic flows, suboptimum temperature regimes, and competition with other species have prevented the Utah sucker from becoming widely distributed and abundant in the Upper Colorado River Basin. Not a threat to the endangered or other native fishes.

Longnose Sucker *Catostomus catostomus*

Native Distribution:

Only member of its family with populations in both North America and Asia. Most widespread sucker of northern North America [Scott and Crossman 1973; Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

Introduced into headwater streams and impoundments of the Colorado River drainage in Colorado and Wyoming. Reported as rare or incidental in Lake Granby and Blue Mesa Reservoir, Colorado, and common in upper reaches of the Gunnison River below Blue Mesa Reservoir [Tyus et al. 1982].

General Habitat:

There is a Habitat Suitability Index Model for longnose sucker [Edwards 1983] that summarizes the species' habitat requirements and preferences.

Generally found in lentic habitats but capable of withstanding strong currents in rivers, as shown by seasonal spawning migrations up tributaries. Prefer clear, cool, deep, oligotrophic lentic habitats [Scott and Crossman 1973; Tyus et al. 1982; Becker 1983].

Examples of Environmental Factors Affecting Distribution or Abundance:

- Generally found at depths of 6-30 m but have been found as deep as 183 m [Scott and Crossman 1973; author unknown, Utah Division of Wildlife Resources].

- Abundance of longnose sucker in Michigan is limited by predation and degradation of spawning areas [Becker 1983].

Temperature.—

- Reported critical thermal maximum was 26.5°C when fish were acclimated at 14°C. Fish selected 11.6°C [Becker 1983; source unknown, Utah Division of Wildlife Resources].

General Behavior:

Although characterized as an insectivore, well suited for herbivory and detritivory. Periphyton constitutes a large portion of the diet in juveniles with insects becoming increasingly important as fish age [Sayigh and Morin 1986].

Reproduction:

Maturation.—Mature at age 2-9 [Carlander 1969]. Typically do not live past 10 years of age but have been reported to live up to 20 years [Scott and Crossman 1973; Lee et al. 1980]. Attain a maximum length of 510-760 mm.

Spawning Requirements.—Spawn primarily in streams 15-30 cm deep, during April-July; occasionally spawn over shallow reefs in lakes. Usually spawn over moderately sized, 0.5-10 cm, gravel. Spawning occurs at temperatures of 5-15°C [Geen et al. 1966; Carlander 1969; Scott and Crossman 1973; Becker 1983].

Spawning Behavior and Biology.—Fish move upstream between noon and midnight. Spawning act lasts about 3-5 seconds and occurs 6-40 times per hour [Trautman 1981]. No nests are built, and eggs are left unattended [author unknown, Utah Division of Wildlife Resources]. Fecundity ranges 14,000-60,000 eggs [Scott and Crossman 1973].

Eggs and Young.—Eggs are demersal, initially adhesive, and have a maximum diameter of 2.8-3.0 mm. Incubation time is 8 d at 15°C, 11 d at 10°C [Geen et al. 1966; Snyder 1981; Trautman 1981]. Total length at hatching is 8-11 mm [Snyder 1981].

Examples of Interactions with Native Colorado River Basin Fishes:

■ Collections of juvenile suckers from middle reaches of the Gunnison River in 1993 contained specimens suspected as hybrids between longnose sucker and native suckers [D. Snyder, Larval Fish Laboratory, Colorado State University, Fort Collins, personal communication].

Options for Control in the Upper Colorado River Basin:

The longnose sucker was the subject of a fish removal projects using gill netting in Pyramid Lake, Alberta, Canada. Although numbers were reduced, the objective of improving trout numbers was not achieved [Rawson and Elsey 1950]. In the Upper Colorado River Basin, the only areas where longnose sucker has been reported are in headwater reservoirs and tributaries (some indication that their range may be expanding as evidenced by collection of suspected hybrids). Presently, not considered an important threat to the endangered or other native fishes.

White Sucker *Catostomus commersoni*

Native Distribution:

Widely distributed in northern, eastern, and central North America [Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

Rare to incidental in the Colorado River below its confluence with the Roaring Fork River, Colorado, and in the Green River downstream of Flaming Gorge Dam. Common in

reaches of the Yampa River above its confluence with the Little Snake River, upstream reaches of the Gunnison River, the Colorado River above its confluence with the Roaring Fork River, in Blue Mesa Reservoir and in Navajo Reservoir. Abundant in Flaming Gorge Reservoir [Tyus et al. 1982].

In a survey of CRB researchers, white sucker ranked eighth (tied with mosquitofish and striped bass) on a list of 28 nonnative fish species considered to adversely impact native fishes of the CRB and the southwestern United States. Suspected impacts included competitive interactions with all native fishes, specifically flannemouth sucker, and hybridization with flannemouth sucker [Hawkins and Nesler 1991].

General Habitat:

There is a Habitat Suitability Index Model and Instream Flow Suitability Curves for white sucker [Twomey et al. 1984] that summarizes the species' habitat requirements and preferences.

A benthic fish that is a habitat generalist found in lakes, reservoirs, streams, and rivers [Becker 1983; Hubert and Rahel 1989; Sublette et al. 1990]. Preferred habitat is warmer, shallow lakes or bays, tributary rivers of large lakes, deep riffles and runs over gravel and cobble substrates, and shaded pools [Scott and Crossman 1973; Tyus et al. 1982; Hubert and Rahel 1989].

Examples of Environmental Factors Affecting Distribution or Abundance:

- Tolerant of wide ranges in environmental conditions including stream gradient, turbidity, and depths [Scott and Crossman 1973; Becker 1983].
- Generally found in rivers at elevations > 1,372 m above sea level [Sublette et al. 1990].
- Generally prefer low velocities, except during spawning, and depths ≤ 46 m [Scott and Crossman 1973].
- Generally found in clear to slightly turbid water, but in Wisconsin, found in the most highly polluted and most turbid waters [Becker 1983].

Temperature.—

- Preferred temperature ranges 10-27°C [Becker 1983; Cincotta and Stauffer 1984; Sublette et al. 1990].

- Critical thermal maximum is 31-32°C [Becker 1983; Sublette et al. 1990].

General Behavior:

Benthic omnivore. Feed on algae, plants, aquatic and terrestrial insects, detritus, mollusks, fish, and fish eggs [Scott and Crossman 1973; Becker 1983].

Reproduction:

Maturation.—May mature in their second year but generally mature at age 3 or age 4. Reported maximum longevity is between 12 and 17 years [Carlander 1969; Becker 1983]. Attain a maximum length of 51-76 cm.

Spawning Requirements.—Over the species' range, spawning occurs from April or May to August; June and July in the Upper Colorado River Basin. Water temperatures during spawning range 7-19°C, usually > 10°C. Spawn in shallow water, usually < 0.3 m, and moderate currents, usually 30-49 cm/second, over sand or gravel. Generally spawn over riffles in streams but will spawn in littoral zones of lakes when river habitat is not available [Carlander 1969; Becker 1983; Sublette et al. 1990; Snyder and Muth 1990].

Spawning Behavior and Biology.—Frequently form large aggregations and migrate to streams or lake shores; may home to certain areas. Spawning generally occurs within a 10 to 14-d period; no nests are built and parents do not guard eggs [Scott and Crossman 1973; Trautman 1981; Becker 1983; Snyder and Muth 1990]. Males arrive at spawning sites 2-3 d before females [Becker 1983]. Reported fecundity ranges 10,000-145,000 eggs per female [Carlander 1969].

Eggs and Young.—Eggs are demersal, initially adhesive, and have a maximum diameter of 2.6-3.3 mm. Incubation period is 5-11 d at 18-10°C. Total length at hatching is 8-10 mm. Larvae remain in gravel 1-2 weeks after hatching, drift as early larvae (usually at night), and subsequently occupy low-velocity shoreline areas [Snyder and Muth 1990].

Examples of Interactions with Native Colorado River Basin Fishes:

- Hybridization with bluehead sucker and flannelmouth sucker [Wick et al. 1981, 1985, 1986; Valdez et al. 1982a, 1982b].

Options for Control in the Upper Colorado River Basin:

In the UCRB, the white sucker is generally found in the clearer, higher gradient, and cooler tributaries and in reservoirs; occasionally found in the mainstem Colorado,

Green, and Yampa rivers. Recent evidence suggests that the species is moving into lower reaches of upper basin rivers [T. Chart, Utah Division of Wildlife Resources, Moab, personal communication], where hybridization with native suckers is likely. Its widespread distribution and tolerance of a wide range of environmental conditions suggest a great potential for the white sucker to spread in the UCRB; monitoring will be important. High turbidity, suboptimal temperatures, and competition with other fishes may be limiting the abundance of white sucker in habitats of endangered species.

Mechanical Removal.—Target spawning aggregations for netting or electrofishing.

Chemical Treatment.—Chemical eradication could be used to reduce white sucker in upper reaches of rivers or in reservoirs where they are common. Target spawning aggregations.

Biological Control.—Options undetermined.

Physicochemical Manipulations.—Options undetermined.

Ictaluridae-Bullhead Catfishes

Black Bullhead *Ameiurus melas*

Native Distribution:

From southern Canada south to the Gulf of Mexico, and from the Rocky Mountains east to the Appalachian Mountains [Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

Rare or incidental in reaches of the Colorado, Duchesne, Green, San Juan, White, and Yampa rivers [Tyus et al. 1982; Nelson et al. 1995].

In a survey of CRB researchers, black bullhead ranked seventh (tied with largemouth bass) on a list of 28 nonnative fish species considered to adversely impact native fishes of the CRB and the southwestern United States. Suspected impacts included predation on young of all native fishes, especially in backwaters, and competitive interactions with native fishes. [Hawkins and Nesler 1991].

General Habitat:

There is a Habitat Suitability Index Model for black bullhead [stuber 1982] that summarizes the species' habitat requirements and preferences.

Found in turbid, vegetated backwaters, oxbows, impoundments, ponds, lakes, and low-gradient streams with muddy bottoms [Sigler and Miller 1963; Becker 1983].

Examples of Environmental Factors Affecting Distribution or Abundance:

- Intolerant of deep, clear, cool habitats [Trautman 1981].
- Tolerant of agricultural siltation and industrial and domestic pollutants [Becker 1983].
- Prefer habitats with low-velocities (< 0.4 cm/s), depths < 1.5 m, and mud, silt, or sand substrates [Becker 1983; Sublette et al. 1990].

Temperature.—

- Critical thermal maximum is 35°C when acclimated at 23°C ; preferred temperature is 21°C [Becker 1983; Sigler and Sigler 1987].

Dissolved Oxygen.—

- Capable of withstanding D.O. concentrations as low as 0.2-0.3 ppm [Becker 1983].

Total Dissolved Solids (TDS).—

Optimum dissolved solids concentrations range 100-600 ppm [Sublette et al. 1990].

General Behavior:

A schooling fish. Benthic, omnivorous scavenger [Becker 1983].

Reproduction:

Maturation.—Mature at ages 2-4 [Carlander 1969; Becker 1983; Sublette et al. 1990]. Typically don't live past 6 years of age and typically don't exceed 250 mm TL; reported up to 380 mm TL [Sigler and Sigler 1987].

Spawning Requirements.—Spawn in shallow areas with muddy substrates and submerged vegetation, debris, or undercut banks starting as early as April and ending as late as August with June and July being peak spawning periods [Scott and Crossman 1973; Becker 1983]. Spawning is initiated when temperatures approach 21°C [Becker 1983].

Spawning Behavior and Biology.—Nests are constructed by females who carry 2,000-6,000 eggs [Sigler and Miller 1963]. Males protect the nests and young fish after they are hatched [Carlander 1969; Becker 1983].

Eggs and Young.—Eggs are demersal, adhesive (adhere together in masses), and have a maximum diameter of 3 mm [Scott and Crossman 1973]. Incubation time is 5-10 d, depending on water temperature [Scott and Crossman 1973; Harlan et al. 1987]. Total length at hatching is 9-10 mm. After hatching, young swim in schools for 2 weeks or longer [Becker 1983].

Examples of Interactions with Native Colorado River Basin Fishes:

■ Colorado squawfish and *Gila* sp. were found in stomachs of black bullhead from the Colorado River near Moab, Utah [Tabata et al. 1965].

■ Young-of-year and yearling Colorado squawfish stocked in ponds along the Colorado River, Colorado, were eaten by black bullhead [Osmundson 1987].

Options for Control in the Upper Colorado River Basin:

Presently, although the black bullhead occurs in several upper basin rivers, it is rare or incidental. Probably not an important threat to the endangered fish species.

Yellow Bullhead *Ameiurus natalis*

Native Distribution:

Eastern and central United States [Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

Found only in Lake Powell; rare or incidental to common [Tyus et al. 1982].

In a survey of CRB researchers, yellow bullhead ranked tenth (tied with reidside shiner and smallmouth bass) on a list of 28 nonnative fish species considered to adversely impact native fishes of the CRB and the southwestern United States [Hawkins and Nesler 1991].

General Habitat:

Common in shallow, clear bays of lakes and ponds and clear, perennial streams that have rocky bottoms and heavy vegetation [Cross 1967; Trautman 1981; Becker 1983].

Examples of Environmental Factors Affecting Distribution or Abundance:

- Do well under adverse conditions. Usually not found in turbid waters [Becker 1983; Sigler and Sigler 1987].
- In Wisconsin, most frequently found in clear waters with a variety of substrates at depths of 0.6-1.5 m [Becker 1983].

Temperature.—

Optimum temperature is 27.6°C [Reynolds and Casterlin 1978].

Dissolved Oxygen.—

- Tolerate D.O. concentrations as low as 0.1-0.3 ppm for short periods. Tolerate D.O. concentration around 2.7 ppm for several days [Becker 1983].

General Behavior:

An omnivorous scavenger.

Reproduction:

Maturation.—Mature in 2-3 years [Carlander 1969; Becker 1983]. Live up to 7 years; attain a maximum length of 380 mm [Becker 1983; Sigler and Sigler 1987].

Spawning Requirements.—Spawn in spring-early summer. Build nests and spawn in shallow areas of lakes and rivers [Carlander 1969; Becker 1983].

Spawning Behavior and Biology.—Spawning occurs over a 2-week period [Becker 1983]. Nests are constructed under overhanging stream banks, in holes, or near stones or stumps [Scott and Crossman 1973]. Females carry 1,652-7,000 eggs [Carlander 1969; Sigler and Sigler 1987].

Eggs and Young.—Eggs are demersal, adhesive (adhere together in masses), and have a maximum diameter of 2.5-3.0 mm. Incubation time is 5-10 d depending on water temperature [Harlan et al. 1987; Sublette et al. 1990]. After hatching, young school near surface and are protected by adults [Becker 1983].

Examples of Interactions with Native Colorado River Basin Fishes:

- Documented predation by yellow bullhead on Colorado squawfish stocked in the Verde River, Arizona [Hendrickson and Brooks 1987].

Options for Control in the Upper Colorado River Basin:

Restricted to Lake Powell. Habitats in upper basin rivers are not suitable for yellow bullhead.

Channel Catfish *Ictalurus punctatus*

Native Distribution:

Central drainages of the United States into southern Canada, and possibly also parts of the Atlantic Coast [Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

First introduced into Utah in 1888 and first introduced into the UCRB in 1892 [Tyus and Nikirk 1988]. The channel catfish is now considered mostly common or abundant throughout much of the upper basin [Tyus et al. 1982; Nelson et al. 1995].

In a survey of CRB researchers, channel catfish ranked first on a list of 28 nonnative fish species considered to adversely impact native fishes of the CRB and the southwestern United States. Suspected impacts included predation on all native fishes, especially larvae and juveniles, and competitive interactions with native fishes. [Hawkins and Nesler 1991].

General Habitat:

There is a Habitat Suitability Index Model for channel catfish [McMahon and Terrell 1982] that summarizes the species' habitat requirements and preferences.

Channel catfish utilize a variety of riverine and lacustrine habitats. Optimum lotic habitats are characterized by warm temperatures and a diversity of velocities, depths, and structural features that provide cover and feeding areas. Optimum lentic habitats are characterized by large surface area, warm temperatures, high productivity, and low to moderate turbidity with abundant cover [McMahon and Terrell 1982]. In the Green and Yampa rivers, Colorado and Utah, channel catfish were most abundant in rocky, turbulent, high-gradient canyon habitats [Tyus and Nikirk 1988]. In the

Yampa River, channel catfish occupy the same habitats throughout the river as the endangered fishes at all times of the year [Irving and Karp 1995].

Examples of Environmental Factors Affecting Distribution or Abundance:

Temperature.—

- Tolerant of temperatures ranging 1-34°C but prefer temperatures of 26-29°C [McMahon and Terrell 1982].
- When acclimated at temperatures ranging 6-30°C, selected temperatures ranging 18.9-30.5°C [Cherry et al. 1975].
- Critical thermal maximum estimated at 33.5-35°C [McMahon and Terrell 1982; Sublette et al. 1990].
- Feed sparingly at 16°C and stop feeding below 10°C [Shipman 1977]; this corresponds with limited growth below 21°C and no growth below 18°C [McMahon and Terrell 1982].
- In the UCRB, growth of channel catfish in the Green River, Colorado and Utah, was less than that reported within its native range [Tyus and Nikirk 1988]. Slow growth may be due to limited resources, suboptimum temperature regimes, short growing seasons, and other unfavorable riverine conditions.

Dissolved Oxygen.—

- Optimum D.O. levels are between saturation and 5 mg/L; critical levels are < 0.8 mg/L [Moss and Scott 1961; McMahon and Terrell 1982].

Hydrogen Ion Concentration (pH).—

- Optimum pH is 6.5-9.0 [Shipman 1977].

Salinity.—

- Salinity tolerances range 2.0-11.4 ppt but will avoid higher concentrations if possible [Allen and Avault 1971; Shipman 1977].
- Growth is slow when salinity concentrations are > 8 ppt and stops at concentrations exceeding 11 ppt [McMahon and Terrell 1982].

Turbidity and Total Dissolved Solids (TDS).—

- Tolerate a wide range of turbidity levels but generally prefer low to moderate turbidity [McMahon and Terrell 1982].
- Turbidity in excess of 85,000 ppm can be fatal [Shipman 1977].
- In the Green River, Utah, periodic die-offs of channel catfish may be caused by heavy input of silt during flash floods which raised turbidity levels [Tom Chart, Utah Division of Wildlife Resources, Moab, personal communication].
- Prefer TDS less than 100 ppm but have been found in habitats with TDS in excess of 350 ppm [McMahon and Terrell 1982].

General Behavior:

Omnivorous, generally benthic feeder; not particular about diet and eat foods that other fish can not utilize [Sigler and Miller 1963; Sigler and Sigler 1987]. Diet includes fish, mice and frogs (dead or alive), plants, seeds, invertebrates, algae, and other things found on the bottom. Channel catfish are most active at night when they move from the deeper waters and protected areas into the shallows to feed [Sigler and Miller 1963].

Reproduction:

Maturation.—Sexual maturity occurs at 18 months to 6 years [Carlander 1969; Sigler and Sigler 1987]. Can live to be over 20 years old but generally only live 10 to 12 years and range in size from 300 to 700 mm TL [Sigler and Sigler 1987]. In the UCRB, channel catfish reported up to 22 years and 756 mm TL, although only 2% were greater than 500 mm TL [Tyus and Nikirk 1988].

Spawning Requirements.—Spawn between early spring and summer when water temperatures range 21-29°C [Sigler and Sigler 1987; Sublette et al. 1990]. Spawn in secluded, darkened areas near shore in rivers and lakes [Scott and Crossman 1973; Pflieger 1975].

Spawning Behavior and Biology.—Males clear nests in areas with undercut banks, logs, or rocks. Females generally spawn only once per year; males can spawn several times in a year [Sublette et al. 1990]. A 0.5-2.0 kg female averages 4,000 eggs per 0.5 kg [Clemens and Sneed 1957]; some females have been reported to carry as many as 70,000 eggs [Carlander 1969].

Eggs and Young.—Eggs are demersal. adhesive (deposited in gelatinous mass), and have a maximum diameter of 3.5 mm. Incubation time is 6-10 d at 15.6-27.8°C. Total length at hatching is 6-9 mm. Young remain in nest for several days after hatching and are defended by adult male. After leaving the nest, young school for several days to several weeks, then disperse [Brown 1942; Canfield 1947; Clemens and Sneed 1957; Saksena et al. 1961; Lippson and Moran 1974].

Examples of Interactions with Native Colorado River Basin Fishes:

- Colorado squawfish were found in stomachs of two of 58 channel catfish (130-452 mm TL) from the Dolores River, collected in 1963 [Coon 1965].
- Remains of humpback chub have been found in stomachs of channel catfish from the Little Colorado River, Arizona [Karp and Tyus 1990b].
- Crescent-shaped wounds on humpback chub were attributed to channel catfish bite marks [Kaeding and Zimmerman 1983; Karp and Tyus 1990b].
- Predation by catfish (channel catfish and flathead catfish *Pylodictis olivaris*) significantly reduced numbers of stocked razorback sucker (45-168 mm TL) during a 3-year reintroduction program in the Gila River, Arizona [Marsh and Brooks 1989].
- In the Green River, Utah, 1980, high diet overlap (index value = 0.60) between Colorado squawfish 22-40 mm TL and channel catfish 15-55 mm TL [McAda and Tyus 1984].
- In the Green River, Colorado and Utah, 1987, biologically important diet overlap (index values > 0.60) occurred between age-0 Colorado squawfish and young-of-year or yearling channel catfish and was primarily attributed to the high relative importance of immature midges in diets of both species [Muth and Snyder 1995].
- Under laboratory conditions, young-of-year juvenile channel catfish ate larvae of Colorado squawfish and razorback sucker. Predation rate and efficiency decreased as larvae developed in the presence of alternative invertebrate prey and in turbid water. Channel catfish were exclusively nocturnal feeders [Muth and Beyers in review].

Options for Control in the Upper Colorado River Basin:

The channel catfish is the nonnative believed to present the greatest threat to native fishes in the UCRB [Hawkins and Nesler 1991]. Controlling channel catfish abundance and

distribution would benefit native fishes. Channel catfish have rarely been a target for eradication or reduction. Channel catfish have demonstrated a relentless ability to recover rapidly and propagate in the upper basin. Controlling channel catfish in the upper basin would be exceedingly difficult if not impossible at this time.

Mechanical Removal.—Channel catfish are vulnerable to depletion through harvesting. In the upper basin, channel catfish are usually small and recreational demand is low [Sigler and Sigler 1987]. Documentation of seasonal congregations could facilitate mechanical removal or chemical treatments.

Chemical Treatment.—Traditional chemical treatments (e.g., rotenone) kill indiscriminantly and are not a viable control option because channel catfish are widely distributed and often sympatric with endangered and other native fishes.

Biological Control.—Channel Catfish Virus Disease (CCVD) impacts only channel catfish. Young are particularly vulnerable to this selective disease which can be fatal 50-95% of the time [Plumb et al. 1989]. Eliminating or reducing stockings or stocking only sterile channel catfish [e.g., Goudie et al. 1983] should be considered.

Physicochemical Manipulations.—Water temperatures in the upper basin approach critical level at which, theoretically, channel catfish growth and reproduction are inhibited. Optimum temperatures for spawning are 24-29°C, whereas growth stops at temperatures below 18°C; mean summer water temperatures throughout the upper basin only average about 21°C for July and August. Lower growth rates for channel catfish in the upper basin have been reported, but natural recruitment does not appear to be affected. Reported sizes of age-0 channel catfish in October (1979-1985) were inversely related to river discharge and positively related with water temperature. High summer flows inundating shoreline nursery habitat and backwaters were more important than water velocity in determining the abundance of channel catfish [Tyus and Nikirk 1988]. High flows had no apparent impact on natural recruitment of channel catfish [Valdez 1990]. However, rapid changes in turbidity during summer flash floods appear to kill channel catfish, and higher flows lower water temperatures.

Esocidae-Pikes

Northern Pike *Esox lucius*

Native Distribution:

The only fish with circumpolar distribution in the Northern hemisphere [Scott and Crossman 1973; Raat 1988]. Its range is restricted to cold and temperate parts of the Northern hemisphere, generally above 40° latitude [Raat 1988]. In North America, ranges from Alaska south to Missouri and Nebraska and east to the Appalachian Mountains.

Distribution and Status in Upper Colorado River Basin:

Widely introduced outside of its native range in North America as a sport fish and as a predator to control other fishes [Scott and Crossman 1973]. In the UCRB, the species was stocked into Elkhead Reservoir, Colorado, in 1977, invaded the Green River, Colorado and Utah, by 1981, and has subsequently increased in range and abundance [Tyus and Beard 1990]. Northern pike inhabit several rivers and impoundments in the upper basin but are infrequently sampled, except in the Yampa and upper Green rivers, where they are routinely collected during ISMP sampling [Chuck McAda, USFWS, personal observation]. Northern pike have been found in Lake Powell, several tributaries including the Yampa, White, Gunnison, and San Juan rivers, the mainstem Colorado River near its confluence with the Gunnison River, and the mainstem Green River from above its confluence with the Yampa River in Lordore Canyon downstream into Desolation Canyon [Tyus et al. 1982; Nelson et al. 1995].

In a survey of CRB researchers, northern pike ranked third on a list of 28 nonnative fish species considered to adversely impact native fishes of the CRB and the southwestern United States. Suspected impacts included predation on all native fishes and competitive interactions with native fishes, especially Colorado squawfish [Hawkins and Nesler 1991].

General Habitat:

There is a Habitat Suitability Index Model for northern pike [Inskip 1982] that summarizes the species' habitat requirements and preferences.

Primarily inhabit vegetated ponds, marshes, large lakes, and slow areas of large rivers [Scott and Crossman 1973; Becker 1983; Raat 1988]. It is a freshwater fish but penetrates weak brackish water in the Baltic Sea [Scott and Crossman 1973]. In

the UCRB, northern pike were primarily captured in "semi-impounded" habitats associated with prominent aquatic and bank vegetation [Tyus and Beard 1990].

Examples of Environmental Factors Affecting Distribution or Abundance:

- Tolerant of a wide range of environmental conditions.
- Prefer low-velocity or lentic habitats; critical maximum velocity is 44 cm/s [Raaf 1988].
- Depth distribution is variable, although generally found at depths < 3 m [Becker 1983].
- Do not do well in turbid water because they are sight feeders; occasionally sampled in turbid water [Scott and Crossman 1973; Becker 1983].

Temperature.—

- Optimum growth and feeding occur at 19-21°C [Raaf 1988; Sublette et al. 1990].
- Can tolerate temperatures approaching 0°C without any stress [Raaf 1988].
- Larvae prefer 21°C with a CTM of 30.8°C, juveniles prefer 26°C with a CTM of 29.8°C, and the final preferendum temperature for adults ranged 23-24°C with a CTM of 32-35°C; all values dependent on acclimation temperatures [Raaf 1988; Sublette et al. 1990].
- Eggs can withstand temperatures ranging 4-23°C [Raaf 1983].

Dissolved Oxygen.—

Tolerate D.O. concentrations > 0.2 mg/L; concentrations ≤ 0.2 mg/L can be lethal [Raaf 1988].

Hydrogen Ion Concentration (pH).—

Have been sampled in waters with pH 3.5-9.5 [Scott and Crossman 1973; Raaf 1988].

Salinity.—

In the Baltic Sea, tolerate salinity concentrations of 0-10‰ [Scott and Crossman 1973; Raat 1988]. In Devil's Lake, North Dakota, the northern pike population was eliminated when salinity rose from 0.8 to 1.5‰ [Becker 1983].

General Behavior:

Fairly sedentary, establishing a territory where cover and food are adequate [Scott and Crossman 1973; Raat 1988].

Tenacious, cannibalistic, voracious, top-predator carnivore. Young-of-year feed on zooplankton and aquatic insects and shift to a diet of fish and other vertebrates as they mature [Scott and Crossman 1973; Becker 1983; Raat 1988]. Size and abundance, not species, are most important in selection of prey [Carlander 1969; Scott and Crossman 1973; Raat 1988].

Reproduction:

Maturation.—Males mature in 1-5 years, and females mature in 2-6 years [Carlander 1969; Scott and Crossman 1973; Raat 1988]. Generally live for 12-24 years; maximum longevity is reported to be 75 years in captivity [Carlander 1969; Scott and Crossman 1973]. Grow up to 609 mm TL in 2 years and reach maximum lengths of 1,270-1,524 mm [Carlander 1969; Raat 1988].

Spawning Requirements.—Spawn in the late winter and spring soon after ice off [Scott and Crossman 1973]. Begin congregating in spawning areas when temperatures range 1.1-4.4°C and spawn when temperatures range 4.4-11.1°C (perhaps up to 18.5°C), peaking at 8.4°C [Carlander 1969; Scott and Crossman 1973; Sublette et al. 1990]. Spawn in heavily vegetated, shallow flood plains of rivers, marshes, and bays of larger lakes [Becker 1983]. Success of spawning depends on high water levels in spring and early summer [Sublette et al. 1990].

Spawning Behavior and Biology.—Spawning occurs over a 2 to 5-d period, no nests or protection are provided for the young [Scott and Crossman 1973; Becker 1983]. Fecundity has been estimated to be 9,000 eggs per 0.5 kg per female with an average of 32,000 eggs per female [Scott and Crossman 1973]. Believed that temperature, light intensity, and presence of suitable vegetation stimulate spawning [Becker 1983].

Eggs and Young.—Eggs are adhesive and have a maximum diameter of 2.3-3.2 mm. Incubation time is 5-26 d, usually 12-14 d [Sublette et al. 1990]. Total length at hatching is 6.5-10 mm. Feeding begins about 10 d after hatching (11-12 mm TL) [Fish 1932; Becker 1983].

Examples of Interactions with Native Colorado River Basin Fishes:

- Ate nine nonnatives, red shiner and fathead minnow being most common, and three natives (speckled dace, bluehead sucker and flannelmouth sucker) [Tyus and Beard 1990].
- Adult Colorado squawfish share habitats with northern pike, suggesting the potential for competitive interactions [e.g., Wick et al. 1985; Tyus and Karp 1989; Tyus and Beard 1990].

Options for Control in the Upper Colorado River Basin:

Although widely distributed in the upper basin, abundance is low, but possibly increasing [McAda et al. 1994]. Northern pike are routinely sampled in the Yampa and upper Green rivers during ISMP sampling. The species is especially common in the Yampa River where they have outnumbered Colorado squawfish in 8 of 9 years of data collection [McAda et al. 1994]. Despite low numbers in most locations, piscivorous habits combined with evidence of increasing populations and sympatry with endangered fishes make northern pike one of the nonnative species of highest concern [Tyus and Beard 1990; Hawkins and Nesler 1991]. Northern pike were stocked as a sportfish in headwater reservoirs and tributaries and have moved downstream into habitats of endangered fishes. The relatively small number of northern pike in mainstem rivers suggests that turbid waters, lack of lentic habitat, competition, or possibly a combination of these and other environmental factors limit the ability of this species to propagate and prosper. Monitoring of northern pike populations throughout the basin is required.

Mechanical Removal.—Several options are available for reducing the abundance of northern pike including increasing fishing pressure, installing barriers that would prevent fish from moving downstream, and netting, electrofishing, and/or trapping back waters, sloughs, etc. during spring spawning aggregations.

Chemical Treatment.—Using fish toxicants to eradicate spawning aggregations is an option if appropriate consideration is given to minimizing potential loss of native fishes.

Biological Control.—Options undetermined. Stocking of northern pike in headwater reservoirs and streams should be discontinued (stocking programs for northern pike have been discontinued by Colorado and Utah).

Physicochemical Manipulations.—Options undetermined.

Cyprinodontidae-Killifishes

Plains Topminnow *Fundulus sciadicus*

Native Distribution:

Two apparently disjunct centers of distribution: one in Nebraska, overlapping into neighboring states, and the other centered in southcentral Missouri and including extreme southeastern Kansas and extreme northeastern Oklahoma [Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

Rare or incidental in the White River, Colorado [Tyus et al. 1982].

General Habitat:

Typically inhabit clear, small- to medium-sized streams with coarse substrates and aquatic vegetation [Cross 1967; Lee et al. 1980]. Also found in pools and quiet backwaters [Lee et al. 1980].

Examples of Environmental Factors Affecting Distribution or Abundance:

- Apparently limited to clear streams and rivers with coarse substrates.

General Behavior:

Probably feed on insects and other aquatic invertebrates.

Reproduction:

Maturation.—Life expectancy is unknown. Typically grow to 38-64 mm TL.

Spawning Requirements.—Spawn in May and June [Cross 1967].

Spawning Behavior and Biology.—Eggs are deposited on aquatic plants or algae mats [Pflieger 1975].

Eggs and Young.—Eggs hatch in 8-10 d at 21°C [Pflieger 1975].

Examples of Interactions with Native Colorado River Basin Fishes:

- None found.

Options for Control in the Upper Colorado River Basin:

Presently, not an important threat to the endangered or other native fishes.

Plains Killifish *Fundulus zebrinus*

Native Distribution:

Southeastern Montana east to Missouri and south into Texas and New Mexico [Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

Rare or incidental in reaches of the Colorado, Gunnison, San Juan, and Yampa rivers [Tyus et al. 1982; Nelson et al. 1995].

In a survey of CRB researchers, plains killifish ranked eleventh (tied with plains minnow, rock bass, sheepshead minnow, Utah chub, bluegill and white crappie) on a list of 28 nonnative fish species considered to adversely impact native fishes of the CRB and the southwestern United States. Suspected impacts included predation on larvae of all native fishes [Hawkins and Nesler 1991].

General Habitat:

Found in shallow, turbid, sandy-bottomed streams, ponds, and rivers [Lee et al. 1980; Sublette et al. 1990]. Often found in water having high alkalinity, salinity, and/or total dissolved solids [Sigler and Miller 1963; Sublette et al. 1990].

Examples of Environmental Factors Affecting Distribution or Abundance:

Little is known about the plains killifish. Found in a variety of water velocities (rapid currents to backwaters) with a preference for slower water < 15 cm deep [Cross 1967; Sublette et al. 1990]. In Kansas, abundant in the west but not in the east; attributed to lower alkalinity and salinity in the east [Cross 1967].

General Behavior:

Omnivorous. Primary foods are insects, other aquatic invertebrates, and floating material [Cross 1967; Carlander 1969].

Reproduction:

Maturation.—Generally do not live past 2 years and are typically 38-100 mm TL [Sublette et al. 1990].

Spawning Requirements.—Spawn in summer months (June-August) over sand and gravel bottoms in shallow water of small pools when temperatures approach 28°C [Carlander 1969; Sigler and Sigler 1987; Sublette et al. 1990].

Spawning Behavior and Biology.—No parental care. Males are not territorial but are aggressive during spawning [Sigler and Sigler 1987]. Known to spawn after a moderate or heavy rain, suggesting that spawning is stimulated by a change in water temperature or influx of fresh water. There may be 3 or 4 separate periods of spawning activity during the spawning season [Pflieger 1975].

Examples of Interactions with Native Colorado River Basin Fishes:

- None found.

Options for Control in the Upper Colorado River Basin:

The limited abundance of plains killifish in the Upper Colorado River Basin suggests that abiotic and biotic factors are not optimum for the species. Further research into habitat and life-history requirements would clarify their status and potential for expansion. Presently, not an important threat to the endangered or other native fishes.

Poeciliidae-Livebearers

Western Mosquitofish *Gambusia affinis*

Native Distribution:

Native to central United States from southern Illinois and Indiana south to Veracruz, Mexico, and Florida, and north along Atlantic slope to southern New Jersey [Sigler and Miller 1963; Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

Introduced worldwide for mosquito control [Lee et al. 1980]. Considered rare or incidental in the UCRB; distribution very spotty [Tyus et al. 1982].

In a survey of CRB researchers, western mosquitofish ranked eighth (tied with striped bass and white sucker) on a list of 28 nonnative fish species considered to adversely impact

native fishes of the CRB and the southwestern United States. Suspected impacts included predation on larvae of all native fishes (*Gila topminnow Poeciliopsis occidentalis* specifically), competition with native fishes (Pecos gambusia *Gambusia nobilis* specifically), and hybridization with Pecos gambusia [Hawkins and Nesler 1991].

General Habitat:

Common or abundant in warm, vegetated ponds, lakes, drainage ditches, and backwaters and oxbows of sluggish streams [Carlander 1969; Lee et al. 1980; Sublette et al. 1990]. Uncommon in moderate to steep gradient streams [Lee et al. 1980]. Prefer slower waters, generally at or near the water surface.

Examples of Environmental Factors Affecting Distribution or Abundance:

- More tolerant to pollutants and chemicals (e.g., rotenone and DDT) than most other fishes [Whitford 1970].

Temperature.—

- Temperatures tolerated range 4.4 to over 37.7°C [Sigler and Miller 1963].
- When acclimated at 15°C, CTM was 35.4°C and critical thermal minimum was 1.5°C. When acclimated at 25°C, CTM was 37.3°C and minimum 14.3°C [Otto 1974].
- Optimum temperature is 31°C [Winkler 1979].

Dissolved Oxygen.—

- Not affected by low D.O. because oxygen at the water surface is utilized [Sigler and Miller 1963].

General Behavior:

Primarily eat mosquito larvae and pupae. Also consume other aquatic insects, zooplankton, diatoms, algae, and occasionally fish [Sigler and Sigler 1987; Sublette et al. 1990].

Reproduction:

Maturation.—Males mature in 4-6 weeks, whereas females mature starting at 6 weeks [Sigler and Sigler 1987; Sublette et al. 1990]. Most fish die in their first year although some may live to 15 months or more with TL of 31-59 mm [Lee et al. 1980; Sigler and Sigler 1987]. Females have indeterminate growth, whereas males stop growing at maturity [Vondracek et al. 1988].

Spawning Requirements.—Can reproduce throughout the year in warm water but generally breed between March and September [Sigler and Miller 1963; Sublette et al. 1990]. Sexual activity in males positively correlated with increased water temperature; sexual activity decreases at temperatures of 16-18°C with complete cessation below 10°C [Haynes 1993].

Spawning Behavior and Biology.—Mosquitofish are live bearers. Females can carry 1-315 embryos, and the gestation period is 21-28 d; 1-5 broods are produced each year [Sigler and Miller 1963; Sublette et al. 1990].

Eggs and Young.—Newborns are 8-9 mm TL [Sigler and Miller 1963].

Examples of Interactions with Native Colorado River Basin Fishes:

■ Interactions with the introduced western mosquitofish are responsible for decline of the native Sonoran topminnow in the lower basin. Predation on juvenile topminnows is a major factor [Meffe 1985].

Options for Control in the Upper Colorado River Basin:

Presently, not considered an important threat to the endangered or other native fishes.

Percichthyidae-Temperate Basses

White Bass *Morone chrysops*

Native Distribution:

Wide ranging throughout the Mississippi and Ohio River valleys and Great Lakes region extending south to the Rio Grande drainage [Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

Widely introduced within and outside of its native range [Lee et al. 1980]. Considered rare or incidental in the UCRB; only occasionally sampled in tributaries of the San Juan River [Tyus et al. 1982].

General Habitat:

There is a Habitat Suitability Index Model and Instream Flow Suitability Curves for white bass [Hamilton and Nelson 1984] that summarizes the species' habitat requirements and preferences.

Commonly found in open water in clear, large lentic habitats and rivers [Sigler and Miller 1963; Lee et al. 1980].

Examples of Environmental Factors Affecting Distribution or Abundance:

■ Thrive over a wide range of limnological conditions. Prefer slower water, generally found within the top 6 m of water. Hard, clear substrates are preferred over unconsolidated substrates. Generally sampled in clear water; high turbidity limits ability to feed, hence limits abundance [Becker 1983].

Temperature.—

■ Critical thermal maximum is 33.5°C, with optimum temperatures ranging 28-29.5°C [Barans and Tubb 1973; Cvancara et al. 1977; Becker 1983].

General Behavior:

A schooling fish typically found in the top 6 m of water [Becker 1983]. A sight-feeding carnivore that feeds on insects, crustaceans, and fish [Becker 1983; Sublette 1990].

Reproduction:

Maturation.—Sexually mature at 2-4 years of age. Longevity ranges 3-4 years in the south up to 8 years in the north [Sigler 1987; Becker 1983]. In Utah Lake, typically 200 to 250 mm TL [Sigler and Miller 1963; Becker 1983].

Spawning Requirements.—A potamodromus spring spawner [Cross 1967; Lee et al. 1980]. Spawn in lake shoals or in river shallows with a clear streambed [Scott and Crossman 1973; Becker 1983]. Optimum spawning temperatures range 16.9-22.6°C, although spawning does occur at water temperatures of 12-26°C [Becker 1983; Sublette et al. 1990].

Spawning Behavior and Biology.—Do not reproduce in smaller lakes, ponds, or impoundments. No nests are built and no parental care is provided for the young [Sigler 1963]. Strong homing instinct to specific spawning areas. Males arrive at spawning sites up to 1 month before females [Pflieger 1975; Sublette et al. 1990]. Fecundity ranges 61,700-994,000 eggs per female [Sublette et al. 1990].

Eggs and Young.—Eggs are demersal, adhesive, and have a maximum diameter of 0.6-1.0 mm [Dorsa and Fritzsche 1979; Sublette et al. 1990]. Incubation time is 4.5 d at 17°C and 1 d at 26°C [Sublette et al. 1990]. Total length at hatching is 1.7-2.8 mm.

Examples of Interactions with Native Colorado River Basin Fishes:

- None found.

Options for Control in the Upper Colorado River Basin:

Not an important threat to the endangered or other native fishes.

Striped Bass *Morone saxatilis*

Native Distribution:

Along the Atlantic Coast and Gulf of Mexico from the St. Lawrence River south to Florida and west to Louisiana [Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

Introduced along the Pacific Coast from the Columbia River south to southern California and in many large, inland freshwater reservoirs [Scofield 1931; Lee et al. 1980]. In 1974, the species was first introduced into Lake Powell, where it has since become established and common [Persons and Bulkley 1982; Tyus et al. 1982]. Cataract Canyon on the Colorado River inflow to Lake Powell prevents striped bass from moving into other parts of the UCRB [Persons and Bulkley 1982; Valdez 1990].

In a survey of CRB researchers, striped bass ranked eighth (tied with western mosquitofish and white sucker) on a list of 28 nonnative fish species considered to adversely impact native fishes of the CRB and the southwestern United States. Suspected impacts included predation on native fishes occurring in Lake Powell (young Colorado squawfish and razorback sucker specifically) and competition with native fishes (Colorado squawfish specifically) [Hawkins and Nesler 1991].

General Habitat:

There is a Habitat Suitability Index Model and Instream Flow Suitability Curves for striped bass [Crance 1984] that summarizes the species' habitat requirements and preferences.

A marine and estuarine coastal species that has been introduced into landlocked reservoirs [Scofield 1931; Nichols 1966; Scott and Crossman 1973]. In landlocked reservoirs and coastal estuaries, juveniles utilize shoreline habitats, whereas adults utilize pelagic zones [Raney 1952; Gustaveson et al. 1982].

Examples of Environmental Factors Affecting Distribution or Abundance:

- Prefer low-velocity habitats except during spring spawning migrations up rivers [Nichols 1966; Scott and Crossman 1973].

Temperature.—

- Distinct thermal preferences at different age classes: young and subadults prefer temperatures of 20-28°C and avoid 30°C; adults prefer temperatures of 16-22°C [Coutant 1985; Matthews et al. 1989].
- Will select depths according to temperature preference. In Lake Powell, preferred temperatures are found in water 15-30 m deep. In Chesapeake Bay, striped bass are sampled as deep as 50 m [Scott and Crossman 1973; Gustaveson et al. 1982].
- Critical thermal maximum for adults is 27-28°C for up to one month and 29°C for short periods [Zule et al. 1990].
- At 11-12°C and/or in acidic waters, larval survival is reduced [Uphoff 1989].

Dissolved Oxygen.—

Larvae and juveniles selected D.O. concentrations > 6 mg/L, and adults selected D.O. levels > 2-3 mg/L [Uphoff 1989].

Hydrogen Ion Concentration (pH).—

- Larvae prefer pH levels of 7.0-9.5; pH levels < 6.8 were frequently lethal [Uphoff 1989].

Salinity.—

- Elevated hardness is beneficial to larvae, and low-level salinity from diluted sea water (0.5-10%) or from NaCl (1.0-1.1%) have a positive effect on larval survival. However, NaCl salinity greater than 2% may be deleterious within the first 10 d of life [Kane et al. 1990]. Salts stabilize pH and provide osmotic balance.

General Behavior:

A schooling fish usually found inshore where at least some current is running. A voracious carnivore that eats fish, crustaceans, and other invertebrates; young-of-year eat zooplankton [Scofield 1931; Nichols 1966]. Like most piscivorous

fishes, striped bass eat forage encountered most frequently. In Lake Powell, threadfin shad *Dorosoma petenense* is the primary food [Persons and Bulkley 1982].

Reproduction:

Maturation.—Males mature at 2-5 years of age, and females mature at 3-6 years [Scofield 1931; Scott and Crossman 1973; Sigler and Sigler 1987]. Can live over 40 years, weigh up to 57 kg, and range 400-2,000 mm TL [Scofield 1931; Scott and Crossman 1973].

Spawning Requirements.—Frequently spawn in turbulent, muddy, silt-laden areas of large rivers characterized by rapids, boulders, and strong currents [Raney 1952; Robison and Buchanan 1988]. Spring spawner that will spawn in fresh or brackish water [Nichols 1966; Scott and Crossman 1973]. Spawning occurs in temperatures ranging 10-24°C, with peak spawning at 15-20°C [Gustaveson et al. 1982; Robison and Buchanan 1988].

Spawning Behavior and Biology.—An anadromous fish (although able to complete their life cycle in fresh water) that has some homing instincts, traveling over 300 km up coastal rivers to spawn [Raney 1952; Nichols 1966; Scott and Crossman 1973; Gustaveson et al. 1982]. Females spawn only once per year, generally over a 1 to 2-d period [Nichols 1966]. Fecundity ranges from 14,000 eggs in a 1.4 kg fish to over 3 million in a 23 kg fish; typically each female carries 180,000-700,000 eggs [Nichols 1966; Scott and Crossman 1973; Sigler and Sigler 1987]. In Lake Powell, striped bass spawn in Gypsum Canyon (near the mixing zone of the reservoir and the Colorado river), Cataract Canyon, and near Glen Canyon dam; fish rarely move through Cataract Canyon [Gustaveson et al. 1982; Persons and Bulkley 1982; Valdez 1990].

Eggs and Young.—Eggs are buoyant or semi-buoyant and are carried along by currents; eggs remain suspended in the water column for approximately 48 h before hatching [Gustaveson et al. 1982]. Maximum egg diameter is 3.2-4.6 mm. Incubation time is 62 h at 15°C, 51 h at 18°C, and 34 h at 21°C [Sigler and Sigler 1987]. Total length at hatching is 2.0-4.0 mm.

Examples of Interactions with Native Colorado River Basin Fishes:

■ Of 321 adult striped bass from Lake Powell analyzed for stomach contents, none contained native threatened or endangered Colorado River fishes [Persons and Bulkley 1982]. Colorado squawfish of suitable size were available in areas sampled but were not identified in the striped bass stomachs examined.

Options for Control in the Upper Colorado River Basin:

The major concern regarding presence of striped bass in Lake Powell is the potential for predation on native fishes (young and adults). Striped bass will not become established in upper basin rivers. Striped bass form the basis of an important sport fishery in Lake Powell, and attempts to reduce numbers of striped bass would be met with strong resistance.

Mechanical Removal.—Increasing fish harvest and targeting spawning aggregations for netting or electrofishing are possible alternatives for reducing striped bass numbers.

Chemical Treatment.—Using fish toxicants to reduce spawning aggregations is an option if appropriate consideration is given to minimizing potential loss of native fishes.

Biological Control.—Options undetermined.

Physicochemical Manipulations.—Options undetermined.

Centrarchidae-Sunfishes

Green Sunfish *Lepomis cyanellus*

Native Distribution:

North America east of the Continental Divide and west of the Appalachian Mountains, from the Great Lakes region south to the gulf coastal states and into northeastern Mexico [Lee et al. 1980; Sublette et al. 1990].

Distribution and Status in Upper Colorado River Basin:

Widely introduced throughout the United States and in Germany [Lee et al. 1980]. In the UCRB, green sunfish are common in Lake Powell and in the Green River near Ouray, Utah; widely distributed elsewhere but considered rare or incidental [Tyus et al. 1982; Nelson et al. 1995].

In a survey of CRB researchers, green sunfish ranked fifth (tied with fathead minnow) on a list of 28 nonnative fish species considered to adversely impact native fishes of the CRB and the southwestern United States. Suspected impacts included predation on young of native fishes (especially Colorado squawfish and razorback sucker) and competition with native fishes (Colorado squawfish in particular) [Hawkins and Nesler 1991].

General Habitat:

There is a Habitat Suitability Index Model for green sunfish [Stuber et al. 1982b] that summarizes the species' habitat requirements and preferences.

Usually inhabit quiet pools in warm, vegetated, shallow waters of ponds, lakes, and rivers with low gradients [Carlander 1977; Becker 1983].

Examples of Environmental Factors Affecting Distribution or Abundance:

- Tolerant of various physicochemical extremes.
- Prefer low-velocity or lentic habitats; rarely sampled in swift waters [Scott and Crossman 1973; Becker 1983].
- Generally found in water < 1.5 m deep over a variety of substrates [Becker 1983].
- Intraspecific densities and interspecific predation or competition can limit abundance of green sunfish [Carlander 1977; Sigler and Sigler 1987].
- Tolerant of clear or turbid water. Can tolerate more turbidity and silt than most other sunfishes [Carlander 1977].

Temperature.—

- Optimum summer temperatures range 26.8-28.2°C [Carlander 1977].
- Preferred temperatures range 16.9-30.6°C, depending on acclimation temperature. Critical thermal maximum was 33 to 36°C. Can withstand temperature shocks of up to $\pm 11^{\circ}\text{C}$ [Sigler and Miller 1963; Cherry et al. 1975; Carlander 1977].

Dissolved Oxygen.—

Complete mortality when exposed to D.O. concentrations of 1.5 mg/L for 48 h [Becker 1983].

Hydrogen Ion Concentration (pH).—

Tolerate rapid changes in pH; increases from 7.2 to 9.6 and decreases from 8.1 to 6.0. Can withstand alkalinity levels up to 2,000 mg/L [Carlander 1977].

General Behavior:

Generally carnivorous, but will utilize plants if other foods are not available [Scott and Crossman 1973; Becker 1983]. Young-of-year eat zooplankton, and adults feed on insects, other aquatic invertebrates, and fish [Carlander 1977].

Reproduction:

Maturation.—Both males and females mature at 1-3 years of age, depending upon climate [Carlander 1977; Becker 1983]. Seldom get larger than 1 kg and rarely live past 10 years [Carlander 1977].

Spawning Requirements.—Spawn intermittently during late spring-summer in shallow areas protected by rocks, vegetation, or logs [Carlander 1977; Becker 1983]. Spawning occurs at 15.6-28°C [Scott and Crossman 1973].

Spawning Behavior and Biology.—Breeding activities occur every 8-9 d throughout the spawning season [Becker 1983]. Males build and guard nests until eggs are hatched [Carlander 1977; Becker 1983]. Fecundity estimates range 15,000-50,000 eggs [Carlander 1977].

Eggs and Young.—Eggs are demersal, adhesive, and have a maximum diameter of 1-1.4 mm. Incubation time is 3 d at 21.1°C, 50 h at 23.8°C, 35-55 h at 24-27°C, and 31 h at 27.1°C. Total length at hatching is 3.6-3.7 mm [Childers 1967; Meyer 1970; Scott and Crossman 1973; Taubert 1977].

Examples of Interactions with Native Colorado River Basin Fishes:

■ Predation by green sunfish on razorback sucker larvae in an isolated backwater on the shores of Lake Mohave was documented with the discovery of an average of four razorback sucker in nearly 40% of green sunfish collected during a 24-h period; total mortality of razorback sucker in the backwater was attributed to predation [Marsh and Langhorst 1988].

■ Young-of-year and yearling Colorado squawfish stocked in ponds along the Colorado river, Colorado, were eaten by green sunfish [Osmundson 1987].

■ In the Green River, Colorado and Utah, 1987, biologically important diet overlap (index values > 0.60) occurred between age-0 Colorado squawfish and green sunfish and was primarily attributed to the high relative importance of immature midges and zooplankton in diets of both species [Muth and Snyder 1995].

■ Observations on behavioral interactions under laboratory conditions suggested that in shared habitats, green sunfish may adversely affect growth and survival of age-0 Colorado squawfish [Karp and Tyus 1990a].

■ Under laboratory conditions, juvenile green sunfish ate larvae of Colorado squawfish and razorback sucker. Predation rate and efficiency decreased as larvae developed, during darkness, in the presence of alternative invertebrate prey, and in turbid water [R. Muth and D. Beyers, unpublished data].

Options for Control in the Upper Colorado River Basin:

Of all the centrarchids in the Upper Colorado River Basin, the green sunfish is the most abundant and best suited for adapting to present environmental conditions. Its piscivorous habits and sympatry with native fishes in low-velocity nursery habitats are reasons for concern. Further research on green sunfish in the upper basin would provide valuable information concerning the impact they have on native fishes and options for controlling their abundance.

Mechanical Removal.—Increasing fish harvest and targeting spawning aggregations for netting or electrofishing are possible alternatives for reducing green sunfish numbers. Green sunfish probably move into rivers from off-channel habitats where they spawn [Osmundson and Kaeding 1991]. Isolating these habitats from river channels and/or mechanically or chemically eradicating green sunfish when they congregate to spawn would facilitate reducing their abundance.

Chemical Treatment.—Using fish toxicants to reduce spawning aggregations in off-channel impoundments is an option if appropriate consideration is given to minimizing potential loss of native fishes.

Biological Control.—Options undetermined. Discontinue stocking green sunfish in off-channel impoundments.

Physicochemical Manipulations.—Options undetermined.

Bluegill *Lepomis macrochirus*

Native Distribution:

Eastern and central North America from the Great Lakes south to the gulf coast and northeastern Mexico [Lee et al. 1980; Sublette et al. 1990].

Distribution and Status in Upper Colorado River Basin:

Widely introduced throughout the United States, Europe, and South Africa [Carlander 1977; Lee et al. 1980]. In the UCRB, occurrence in rivers is very spotty and rare or incidental; common in Lake Powell and Navajo Reservoir [Tyus et al. 1982].

In a survey of CRB researchers, bluegill ranked eleventh (tied with plains minnow, rock bass, sheepshead minnow, Utah chub, plains killifish and white crappie) on a list of 28 nonnative fish species considered to adversely impact native fishes of the CRB and the southwestern United States. Suspected impacts included competition with native fishes [Hawkins and Nesler 1991].

General Habitat:

There is a Habitat Suitability Index Model for bluegill [Stuber et al. 1982a] that summarizes the species' habitat requirements and preferences.

Inhabit shallow, perennial, clear, warm lakes, ponds, and slow moving rivers and creeks with abundant aquatic vegetation [Carlander 1977; Becker 1983].

Examples of Environmental Factors Affecting Distribution or Abundance:

- Tolerant of a wide range of environmental factors.
- Prefer low-velocity and lentic habitats; optimum velocities are < 10 cm/s, but bluegill can tolerate currents up to 45 cm/s [Stuber et al. 1982a].
- Utilize the entire water column depending upon season, temperature, and cover [Becker 1983].
- Sampled over a variety of substrates but prefer sand and gravel [Carlander 1977; Becker 1983].
- Sight feeder, enhancing affinity for clear to slightly turbid water [Becker 1983].

Temperature.—

- Optimum feeding temperature is 27°C [Becker 1983].
- Optimum temperatures range 28-32°C; CTM is typically 35.5-36.5°C [Carlander 1977]. When acclimated at temperatures ranging 6-30°C, selected temperatures ranging 18-32°C [Cherry et al. 1975].

Dissolved Oxygen.—

- Tolerate D.O. concentrations as low as 0.75 mg/l during the winter but generally avoid concentrations < 3.0 mg/l. Often the first fish species to die in winterkill lakes [Carlander 1977; Becker 1983].

Hydrogen Ion Concentration (pH).—

- Can survive pH of 4.0-10.35 [Carlander 1977]. Optimum pH levels range 6.5-8.5 [Stuber et al. 1982a].

Salinity.—

- Have been sampled in waters with salinity concentrations as high as 5.6 ppt; prefer salinity concentrations below 3.6 ppt [Carlander 1977; Stuber et al. 1982a].

General Behavior:

A schooling fish. Omnivore, prefer macroinvertebrates and fish, but utilize plants when other foods are limited [Carlander 1977].

Reproduction:

Maturation.—Both sexes mature as early as the first summer of life or as late as the third summer [Carlander 1977]. Bluegill are usually larger than green sunfish (bluegill may grow to 400 mm TL) and live up to 11 years; typically, bluegill live 1-4 years and are 178-300 mm long [Carlander 1977; Stuber et al. 1982a].

Spawning Requirements.—Spawn intermittently during April-August when water temperatures range 17-32°C; optimum temperatures are 22-27°C [Sigler and Miller 1963; Carlander 1977; Stuber et al. 1982a].

Spawning Behavior and Biology.—Males build nests in shallow water preferably over fine gravel [Carlander 1977]. Males guard the nests for several days after larvae have hatched [Sigler and Miller 1963; Carlander 1977]. Fecundity estimates range 3,000-60,000 eggs [Carlander 1977].

Eggs and Young.—Eggs are demersal, adhesive, and have a maximum diameter of 1-1.4 mm. Incubation time is 71 h at 22.6°C, 34 h at 27°C, and 32.5 h at 27.3°C. Total length at hatching is 2-3 mm [Becker 1983].

Examples of Interactions with Native Colorado River Basin Fishes:

- None found.

Options for Control in the Upper Colorado River Basin:

Bluegill are presently not a threat. The limited distribution and low abundance of bluegill in upper basin rivers suggest that environmental conditions are suboptimum. Probable limiting factors are low water temperatures, suboptimum spawning and feeding temperatures, high turbidity, lack of lentic habitat, competition with other fishes, and swift currents. Future options for limiting abundance of bluegill include eliminating stocking, increasing harvest, and limited chemical treatment of spawning aggregations in Lake Powell and Navajo Reservoir. Bluegill have been targeted in several abundance control projects because they frequently overpopulate areas and become stunted [Wydoski 1992].

Smallmouth Bass *Micropterus dolomieu*

Native Distribution:

From the Great Lakes south to the Tennessee River system in Alabama and west to eastern Oklahoma [Carlander 1977; Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

Widely transplanted throughout the United States and abroad [Carlander 1977; Lee et al. 1980]. In the UCRB, scattered distribution along the Green River in Utah, but rarely sampled except near Ouray where the species is common. The species is now routinely collected in the Yampa and upper Green rivers during ISMP sampling [McAda et al. 1994]. Also found in reaches of the Yampa, Gunnison, and Duchesne rivers and in Flaming Gorge and Navajo reservoirs; rare or incidental [Tyus et al. 1982; Nelson et al. 1995].

In a survey of CRB researchers, smallmouth bass ranked tenth (tied with yellow bullhead and redbreast shiner) on a list of 28 nonnative fish species considered to adversely impact native fishes of the CRB and the southwestern United States. Suspected impacts included predation on young of native fishes (endemic fishes of the Gila River Basin mentioned specifically) [Hawkins and Nesler 1991].

General Habitat:

There is Habitat Suitability Information for smallmouth bass [Edwards et al. 1983] that summarizes the species' habitat requirements and preferences.

Prefer clear, wide, fast-flowing rivers and large lakes with rocky and sand bottoms; do not show a strong preference for vegetated areas [Scott and Crossman 1973; Carlander 1977; Becker 1983; Rankin 1986].

Examples of Environmental Factors Affecting Distribution or Abundance:

- Temperature requirements of smallmouth bass make wide, clear streams more suitable habitat in the southern part of its range and deep, clear lakes more suitable habitat in the northern part. Avoid sluggish and muddy waters [Carlander 1977].
- Can tolerate a wide range of velocities and found in the epilimnion of lentic environments [Carlander 1977].
- Prefer coarse substrates, depths > 45 cm, and velocities ≤ 20 cm/s [Rankin 1986].
- Because smallmouth bass are sight feeders, prefer clear water and rarely sampled in turbid water [Becker 1983].
- Loss of eggs and larvae has been attributed to floods, receding water levels, predation, fungus, rapid temperature changes, nest desertion, and spawning in nests of other species [Carlander 1977].

Temperature.—

- Temperature is one of the most important environmental variable affecting smallmouth bass distribution and abundance. Optimum temperatures have been reported to be anywhere from 20 to 31°C, depending upon acclimation temperatures and environment [Cherry et al. 1975].
- Critical thermal maximum ranges 29-37°C, with 37°C being the reported maximum independent of acclimation temperature [Carlander 1977; Becker 1983; Armour 1993].
- Become lethargic and feed minimally at temperatures < 10°C [Carlander 1977; MacLean et al. 1980].

■ Larvae and early juveniles are particularly sensitive to temperature. Distribution and year class success are dependent upon growing to a size sufficiently large to survive winter which requires at least 100 frost-free days [MacLean et al. 1980; Searns 1982; Hubert 1988].

Dissolved Oxygen.—

■ D.O. concentrations < 1.0 mg/L can be lethal, optimum concentration are > 6.0 mg/L [Carlander 1977; Becker 1983].

Hydrogen Ion Concentration (pH).—

■ Research results suggest that the smallmouth bass is one of the first species of sport fish to be extirpated as lakes acidify, but field testing is limited [Snucins and Shuter 1991]. Tolerated decreases in pH from 9.3-6.0 and increases from 7.7 to 9.7; have been sampled in water with pH levels as low as 4.9 [Carlander 1977; Snucins and Shuter 1991].

■ Young died in lakes with pH of 4.9-5.9 and total aluminum concentrations of 55-215 $\mu\text{g/l}$ [Snucins and Shuter 1991].

■ Critical pH reported at 5.1 [Holtze and Hutchinson 1989].

General Behavior:

Non-migratory, crepuscular fish that only schools when young [Scott and Crossman 1973; Carlander 1977]. Sight-feeding carnivore that preys on fish, crayfish, and aquatic insects [Becker 1983].

Reproduction:

Maturation.—Typically mature in 3-4 years [Carlander 1977]. Frequently grow to 1.3-2.2 kg (200-560 mm TL) and generally do not live past 10 years [Carlander 1977; Lee et al. 1980].

Spawning Requirements.—Spring spawner that will spawn at temperatures ranging 11-24°C, with optimum spawning temperatures of 16-19°C [Scott and Crossman 1973; Armour 1993]. Spawning coincides with increasing temperature and receding or stable flows; spawning stops with flooding [Sublette et al. 1990]. Spawn in rivers and along shores of lakes (spawn in areas protected from current, waves, or wind) [Hubbs and Bailey 1938].

Spawning Behavior and Biology.—Spawning lasts for 6-10 d [Scott and Crossman 1973]. Males build nests in gravel, preferably associated with natural or artificial structures, in deep (0.4 to 6 m), rocky areas [Becker 1983]. Males protect eggs and larvae for up to 28 d; they will abandon the nest when temperatures drop below 14°C [Becker 1983; Armour 1993]. Fecundity increases with age and size, averaging 2,000-21,000 eggs per female [Carlander 1977].

Eggs and Young.—Eggs are demersal, adhesive, and have a maximum diameter of 1.8-2.8 mm. Incubation time is 9.5 d at 12.8°C and 2.25 d at 23.9°C [Sublette et al. 1990]. Total length at hatching is 4.6-5.0 mm [Reighard 1906].

Examples of Interactions with Native Colorado River Basin Fishes:

- Smallmouth bass apparently displaced roundtail in sections of the Gila River drainage, New Mexico [Bestgen and Propst 1989].

Options for Control in the Upper Colorado River Basin:

High turbidity, competition, predation, and erratic flows have contributed to limiting smallmouth bass in the upper basin. It is a piscivorous species that is moving into habitats of the endangered fishes. Consequently, potential for detrimental impacts on native fishes exists. Specific studies concerning the smallmouth bass and interactions with native fishes have not been completed.

Mechanical Removal.—Increasing angling harvest and using fish barriers to prevent movement into habitats of the endangered fishes could potentially reduce abundance. Spawning aggregations could be targeted for mechanical removal or chemical treatment.

Chemical Treatment.—Poison areas where endangered fishes are not present, such as Starvation Reservoir, Utah, and the upper Duchesne River.

Biological Control.—Options undetermined. Discontinue stocking smallmouth bass in off-channel impoundments.

Physicochemical Manipulations.—Options undetermined; replicating natural river conditions of variable flows and temperatures and high turbidity would discourage smallmouth bass movement into habitats of endangered fishes. Floods in 1983 and 1984 in the Gila River drainage severely reduced numbers of smallmouth bass [Bestgen and Propst 1989].

Largemouth Bass *Micropterus salmoides*

Native Distribution:

Difficult to determine precisely due to numerous undocumented transplants; however, believed that largemouth bass ranged from northeastern Mexico east to Florida and north to southern Quebec and Ontario [Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

Introduced extensively worldwide [Becker 1983]. In the UCRB, the largemouth bass is abundant in Lake Powell and rare or incidental in the mainstem Colorado and San Juan rivers and in Flaming Gorge Reservoir [Tyus et al. 1982; Nelson et al. 1995].

In a survey of CRB researchers, largemouth bass ranked seventh (tied with black bullhead) on a list of 28 nonnative fish species considered to adversely impact native fishes of the CRB and the southwestern United States. Suspected impacts included predation on young of native fishes (Colorado squawfish and razorback sucker mentioned specifically) and competition with native fishes (Colorado squawfish in particular) [Hawkins and Nesler 1991].

General Habitat:

There is a Habitat Suitability Index Model for largemouth bass [Stuber et al. 1982c] that summarizes the species' habitat requirements and preferences.

Largest centrarchid (500-700 mm TL), consequently, the most important warmwater sportfish in the United States [Becker 1983; Sigler and Sigler 1987]. Usually found in clear, shallow, heavily vegetated littoral zones of lakes and reservoirs, ponds, and sluggish areas of large rivers [Heidinger 1976; Becker 1983].

Examples of Environmental Factors Affecting Distribution or Abundance:

- In general, tolerance to physical and chemical factors falls between the sensitive of salmon/shad and hardy cyprinids/ictalurids [Heidinger 1976].
- Prefer low-velocity and lentic, shallow (< 6 m deep) habitats [Carlander 1977].
- Prefer clear water (turbidity inhibits mating, feeding, and egg survival) but can tolerate some turbidity. Preferred substrates are generally muddy with stumps and

aquatic vegetation, but largemouth bass are sampled in habitats with a variety of substrates [Carlander 1977; Becker 1983].

Temperature.—

- Optimum temperatures range 27.2-30°C. Reported CTM ranges 36-39°C, varying with acclimation temperature [Carlander 1977; Becker 1983].

Dissolved Oxygen.—

- Low tolerance to depleted D.O. levels, avoiding concentrations < 1.5 mg/L. Fish exposed to D.O. concentrations < 3 mg/L have died but generally do not die until concentrations diminish to 0.7-1.4 mg/L [Carlander 1977; Becker 1983].

Hydrogen Ion Concentration (pH).—

- Adults can tolerate pH of 3.9-11.0 and have survived rapid changes from 8.1 to 6, 7.2 to 9.3, 9.2 to 6.1, and 6.1 to 9.5. Young fish are less tolerant to pH levels < 5 and > 10 [Carlander 1977; Becker 1983]. A pH of 5.1 was identified as the critical level in combination with aluminum [Holtze and Hutchinson 1989].

Salinity.—

- Sampled in brackish waters with 24.4 ppt salinity and slightly alkaline waters (< 900 ppm) [Carlander 1977].

General Behavior:

A schooling, sedentary fish found in soft-bottomed areas [Carlander 1977]. Sight-feeding carnivore. Young fish eat microcrustaceans. Older fish eat insects, frogs, crayfish, and fish [Heidinger 1976; Carlander 1977].

Reproduction:

Maturation.—Sexual maturity is related to size not age. Females mature at 250 mm and males at 220 mm TL; anywhere from 1-5 years [Heidinger 1976; Carlander 1977]. Maximum longevity is 6 years for males and 9 years for females [Becker 1983].

Spawning Requirements.—Spawn during the evening from spring to mid summer at water temperatures of 11-24°C [Heidinger 1976; Carlander 1977]. Optimum spawning temperatures range 16-19°C [Scott and Crossman 1973]. Spawn in shallow, protected sites often associated with emergent vegetation.

Spawning Behavior and Biology.—Males build nests in sand, gravel, or soft bottoms where they can expose hard objects [Carlander 1977; Becker 1983]. Males will protect eggs and larvae for several weeks [Heidinger 1976; Becker 1983]. Fecundity estimates range 2,000-109,000 eggs per female with an average of 2,025-15,000 eggs per kg per female [Carlander 1977].

Eggs and Young.—Eggs are demersal, adhesive, and have a maximum diameter of 1.5-2.0 mm [Scott and Crossman 1973]. Incubation time is 3-5 d at 22-19°C [Scott and Crossman 1973; Sublette et al. 1990]. Total length at hatching is 2.3-5.5 mm.

Examples of Interactions with Native Colorado River Basin Fishes:

- Young-of-year and yearling Colorado squawfish stocked in ponds along the Colorado river, Colorado, were eaten by largemouth bass [Osmundson 1987]. Colorado squawfish was the selected forage fish.

- Documented predation by largemouth bass on Colorado squawfish stocked in the Verde River [Hendrickson and Brooks 1987].

Options for Control in the Upper Colorado River Basin:

Piscivory combined with an affinity for low-velocity habitats are reasons for concern over the impacts largemouth bass might have young native fishes. High turbidity, variable flows, competition, and absence of quality spawning areas contribute to the low numbers and small size of largemouth bass in the upper basin. Largemouth bass populations have been manipulated using chemical poisoning and electrofishing in littoral zones [McHugh 1990].

Mechanical Removal.—Increasing angling harvest, installing fish barricades to reduce downstream migration, and netting or electrofishing spawning aggregations are all possible control options. Speculated that young largemouth bass migrate into the river from protected off-channel spawning areas [Osmundson and Kaeding 1991]. Isolating these habitats from the main channel and/or mechanically or chemically eradicating adults when they congregate to spawn would facilitate reducing abundance.

Chemical Treatment.—Localized chemical eradication is an option.

Biological Control.—Eliminate stocking or stock only sterile fish in impoundments.

Physicochemical Manipulations.—Options undetermined. The largemouth bass is primarily a lentic species that has adapted to low-velocity riverine habitats. Accordingly, higher flows would probably negatively impact largemouth bass, but this has not been documented in the UCRB.

White Crappie *Pomoxis annularis*

Native Distribution:

Freshwaters of east central North America from Minnesota west to the Appalachian Mountains south to the Gulf Coast and west to Texas [Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

Widely introduced throughout the United States [Lee et al. 1980]. In the UCRB, rare or incidental in Navajo Reservoir [Tyus et al. 1982].

In a survey of CRB researchers, white crappie ranked eleventh (tied with plains minnow, rock bass, sheepshead minnow, Utah chub, plains killifish and bluegill) on a list of 28 nonnative fish species considered to adversely impact native fishes of the CRB and the southwestern United States [Hawkins and Nesler 1991].

General Habitat:

There is a Habitat Suitability Index Model for white crappie [Edwards et al. 1982b] that summarizes the species' habitat requirements and preferences.

Found in streams, lakes, ponds, and slow to moderate currents of large rivers [Scott and Crossman 1973; Becker 1983].

Examples of Environmental Factors Affecting Distribution or Abundance:

■ Have a greater tolerance for higher turbidity, temperatures, and velocities than the black crappie. Better adapted to turbid conditions than other centrarchids and do well in clear waters; however, they are outcompeted in clear waters when other centrarchids are present. Depths at which white crappie are found vary with season [Carlander 1977; Becker 1983].

Temperature.—

- Optimum temperatures are 27-29° C; can tolerate temperatures up to about 31°C [Becker 1983; Sigler and Sigler 1987].

Dissolved Oxygen.—

- In one study, avoided areas where D.O. concentrations were < 3.3 ppm [Becker 1983].

Hydrogen Ion Concentration (pH).—

- Tolerate pH of 6.2-9.6 [Becker 1983].

General Behavior:

A schooling, relatively sedentary fish. Opportunistic carnivore. Young feed on zooplankton and crustaceans, and adults eat a variety of foods including aquatic insects and fish [Carlander 1977; Sigler and Sigler 1987].

Reproduction:

Maturation.—Typically mature at 2-4 years of age [Sigler and Sigler 1987]. Rarely exceed 355 mm TL and typically do not live past 5 years; some have reportedly reached 10 years [Scott and Crossman 1973; Carlander 1977].

Spawning Requirements.—Spawn in late spring and early summer at temperatures of 14-23°C, peaking at 16-20°C [Carlander 1977; Becker 1983; Sigler and Sigler 1987]. Spawn in shallows (5-150 cm deep) near rooted plants and algae under protected banks (if available) with hard clay, gravel, or aquatic-root bottoms [Carlander 1977; Becker 1983].

Spawning Behavior and Biology.—Nests are constructed by males. Males protect eggs and larvae (unlike most centrarchids, do not abandon nests when temperatures drop) [Becker 1983]. Fecundity estimates range 7,000-368,000 depending upon climate and size or age of female [Carlander 1977].

Eggs and Young.—Eggs are demersal, adhesive, and have a maximum diameter of 0.8-0.9 mm [Becker 1983]. Incubation time is 27-93 h, depending on temperature [Sublette et al. 1990]. Total length at hatching is 1.2-2.6 mm [Siefert 1968].

Examples of Interactions with Native Colorado River Basin Fishes:

- None found.

Options for Control in the Upper Colorado River Basin:

The white crappie has a higher tolerance for turbidity and currents than other centrarchids and therefore better suited for typical habitats in rivers of the UCRB. However, their occurrence in the upper basin is extremely limited and probably due to lack of introductions in impoundments. Potential exists for the species to invade nursery habitats of native fishes and adversely impact the native community. Accordingly, white crappie should not be stocked in upstream impoundments. It may be prudent to control white crappie (i.e., increase harvest) in Navajo Reservoir to reduce chances of movement into the San Juan River.

Black Crappie *Pomoxis nigromaculatus*

Native Distribution:

The Atlantic Coast from Florida to Virginia, south along the Gulf Coast to central Texas, north to North Dakota and east to the Appalachian Mountains [Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

Widely introduced throughout the United States [Lee et al. 1980]. In the UCRB, common in Lake Powell and rare or incidental in middle reaches of the mainstem Colorado River, lower San Juan River, headwater tributaries of the San Juan River, and in Navajo Reservoir [Tyus et al. 1982]. Recently found in nursery habitats of the Green River near Ouray [Utah Division of Wildlife Resources, personal communication].

General Habitat:

There is a Habitat Suitability Index Model for white crappie [Edwards et al. 1982a] that summarizes the species' habitat requirements and preferences.

Inhabit the clear, warm, quiet waters of ponds, small lakes, bays of large lakes, and backwaters of large rivers [Carlander 1977; Becker 1983]. Generally found where there is abundant aquatic vegetation; reproduction and larval/juvenile growth are dependent on vegetation [Carlander 1977; Edwards et al. 1982a]. Generally prefer clearer, cooler, and deeper water than white crappie *Pomoxis annularis* [Scott and Crossman 1973].

Examples of Environmental Factors Affecting Distribution or Abundance:

- Prefer lentic habitats and currents < 10 cm/s but not > 60 cm/s. Absent from rivers where the gradient exceeds 2 m/km [Edwards et al. 1982a].
- Prefer clear water with muddy-sandy bottoms [Carlander 1977].

Temperature.—

- Temperature preferences range 24-30°C; no CTM has been established [Carlander 1977; Edwards et al. 1982a].

Dissolved Oxygen.—

- In supersaturated waters, black crappie died. The minimum D.O. level tolerated has been reported to be 0.3-1.4 mg/L [Sigler and Miller 1963; Carlander 1977].

Salinity.—

- Tolerate mild brackish waters with 4.7 ppt salinity [Carlander 1977].

General Behavior:

A schooling fish. Mid-water carnivore that primarily eats invertebrates during first 3 years of life, later becoming primarily piscivorous [Scott and Crossman 1973; Carlander 1977].

Reproduction:

Maturation.—Sexual maturity is achieved in 1-3 years [Carlander 1977]. Maximum longevity is 13 years, with adults typically growing to 130-420 mm TL and weighing 450 g [Sigler and Miller 1963; Carlander 1977].

Spawning Requirements.—Spawn in spring and early summer when water temperatures range 14-23°C; optimum spawning temperatures are 17-20°C [Carlander 1977].

Spawning Behavior and Biology.—Males build nests in shallow (0.2-0.6 m deep), vegetated littoral zones with sand, gravel, or mud bottoms [Carlander 1977; Becker 1983]. Fecundity estimates range 3,000-188,000, depending on size or age of female [Carlander 1977].

Eggs and Young.—Eggs are demersal, adhesive, and have a maximum diameter of 0.9 mm. Incubation time is 3-5 d [Scott and Crossman 1973]. Total length at hatching is 2.3 mm [Siefert 1969].

Examples of Interactions with Native Colorado River Basin Fishes:

- None found.

Options for Control in the Upper Colorado River Basin:

The recent spread of black crappie into nursery habitats of the Green River near Ouray is of concern [Utah Division of Wildlife Resources, personal communication]. The introduction of black crappie into Kenney Reservoir on the White River, Colorado, and the species' subsequent downstream migration is the reason for this recent range extension. However, emigration of large numbers of black crappie from Elkhead Reservoir has had no effect on the fish community in the Yampa River because black crappie have failed to survive or reach habitats of the endangered fishes [Tom Nesler, CDOW, personal communication]. Stunted populations of black crappie have been partially controlled using mechanical removal (fyke nets, seines, electrofishing) or chemical eradication [Hanson et al. 1983].

Mechanical Removal.—Increasing angling harvest, installing fish barricades to reduce downstream movement, and netting or electrofishing spawning aggregations are all possible control options.

Chemical Treatment.—Localized chemical eradication is an option (e.g., in Kenney Reservoir).

Biological Control.—Options undetermined. Discontinue stocking in the upper basin.

Physicochemical Manipulations.—Options undetermined; replicating natural river conditions of variable flows and temperatures and high turbidity would discourage black crappie movement into habitats of endangered fishes. Reproductive control with water level fluctuations in reservoirs is an option.

Percidae-Perches

Iowa Darter *Etheostoma exile*

Native Distribution:

Interior of southern Canada and the northern United States [Lee et al. 1980].

Distribution and Status in Upper Colorado River Basin:

Known only from a few collections in the upper San Juan River and in Lake Granby; rare or incidental [Tyus et al. 1982].

General Habitat:

■ Typical habitats are clear, cool lakes, ponds, and slow-flowing rivers with submerged aquatic vegetation and substrates of sand, peat, or organic debris [Scott and Crossman 1973; Becker 1983]. Generally inhabit the deeper waters of lakes and pools of streams except during the breeding season when they move into shallower waters [Becker 1983].

Examples of Environmental Factors Affecting Distribution or Abundance:

■ Intolerant of turbidity [Scott and Crossman 1973].

Dissolved Oxygen.—

■ D.O. concentrations as low as 2 mg/L are tolerated [Becker 1983].

General Behavior:

Young are primarily planktivorous, becoming insectivorous with age [Scott and Crossman 1973; Becker 1983].

Reproduction:

Maturation.—Probably sexually mature at age 1. Typically do not live past 3 years of age and reach 51-58 mm TL [Scott and Crossman 1973].

Spawning Requirements.—Spawn in spring and early summer at temperatures ranging 12-15°C [Becker 1983].

Spawning Behavior and Biology.—Males initiate spawning by moving out of deeper waters and establishing territories in shallow shorelines of lakes or along banks of streams (current 0.2-0.6 m/s) where there is submerged fibrous vegetation; will utilize gravel or sand if vegetation is not available [Scott and Crossman 1973; Becker 1983]. Fecundity estimates range from 350 to over 2,000 eggs per female, depending on size or age of female [Scott and Crossman 1973].

Eggs and Young.—Eggs are demersal, adhesive, and have a maximum diameter of 1.1 mm [Scott and Crossman 1973]. Incubation time is 18-26 d at 13-16°C. Total length at hatching is 3.4 mm [Jaffa 1917; Becker 1983].

Examples of Interactions with Native Colorado River Basin Fishes:

- None found.

Options for Control in the Upper Colorado River Basin:

Not a threat to the endangered or other native fishes.

Johnny Darter *Etheostoma nigrum*

Native Distribution:

In Canada, from Saskatchewan to Quebec, and in the United States from Colorado to North Carolina and south to Arkansas [Becker 1983].

Distribution and Status in Upper Colorado River Basin:

Known only from a few collections in Lake Granby, Colorado; rare or incidental [Tyus et al. 1982].

General Habitat:

Inhabit a wide variety of habitats but prefer low- to moderate-velocity streams with pools and riffles, sand or gravel substrates, and vegetation [Scott and Crossman 1973; Becker 1983; Ingersoll and Claussen 1984].

Examples of Environmental Factors Affecting Distribution or Abundance:

- An invasive, pioneer species that has broad environmental tolerances [Becker 1983; Propst and Carlson 1989].
- Being a ubiquitous fish, can tolerate many organic and inorganic pollutants [Becker 1983].
- Prefer low- to moderate-velocity habitats usually in shallow areas but have been sampled as deep as 42 m. Select sand or gravel substrates and clear to turbid waters; can tolerate more turbidity than other darters [Scott and Crossman 1973; Becker 1983].
- In Colorado, a decrease in range and abundance was attributed to channelization, urban and agricultural wastes and effluent, and unseasonably high sediment transport [Propst and Carlson 1989].

Temperature.—

- Optimum temperatures range 21-23°C. The CTM is 30-32°C [Ingersoll and Claussen 1984].

Dissolved Oxygen.—

- D.O. concentration < 0.2 ppm were fatal [Becker 1983].

General Behavior:

Diet consists of plants, aquatic insects, algae, organic debris, and silt [Scott and Crossman 1973; Becker 1983; Propst and Carlson 1989].

Reproduction:

Maturation.—Sexually mature in 1 year. Attain lengths of up to 76 mm and live up to 3 years [Becker 1983].

Spawning Requirements.—Spawn in spring and summer when temperatures range 11.7-21.1°C [Scott and Crossman 1973; Becker 1983; Propst and Carlson 1989].

Spawning Behavior and Biology.—Male selects a territory then builds a nest on the underside of some structure and protects the eggs until hatching [Becker 1983]. Fecundity ranges 30-200 clutches for each of 5-6 breeding sessions [Scott and Crossman 1973].

Eggs and Young.—Eggs are demersal, adhesive, and have a maximum diameter of about 1.5 mm. Incubation time is 5-8 d at 22-24°C [Scott and Crossman 1973]. Total length at hatching is 5.0 mm [Fish 1932].

Examples of Interactions with Native Colorado River Basin Fishes:

- None found.

Options for Control in the Upper Colorado River Basin:

Not a threat to the endangered or other native fishes.

Yellow Perch *Perca flavescens*

Native Distribution:

The yellow perch has almost a circumpolar distribution in the Northern Hemisphere [Scott and Crossman 1973; Thorpe 1977]. In North America, it is native to northcentral and northeastern United States and central and eastern Canada [Becker 1983; Sublette et al. 1990].

Distribution and Status in Upper Colorado River Basin:

Limited to tributaries of the San Juan River; rare or incidental [Tyus et al. 1982].

General Habitat:

There is Habitat Suitability Information for yellow perch [Krieger et al. 1983] that summarizes the species' habitat requirements and preferences.

A coolwater fish that lives in a variety of habitats including, lakes, ponds, and quiet waters or rivers [Scott and Crossman 1973]. Most common in clear, open waters with moderate vegetation; rarely found in brackish waters [Becker 1983].

Examples of Environmental Factors Affecting Distribution or Abundance:

- Prefer static or low-velocity habitats but can withstand currents up to 60 cm/s [Thorpe 1977]. Commonly inhabit water < 9.2 m deep with a preference for muck, sand, or gravel bottoms [Scott and Crossman 1973; Becker 1983].

- Stable habitats are an important factor in maintaining populations [Becker 1983].

- Have an affinity for clear water because turbid water reduces spawning and feeding success [Thorpe 1977; Becker 1983].

Temperature.—

- Prefer 20°C; CTM estimates range 26-33°C [Thorpe 1977; Reynolds and Casterlin 1979].

Dissolved Oxygen.—

- More tolerant to low D.O. than sunfishes; lethal minimum concentrations range 0.25-2.25 mg/L, depending on temperature [Thorpe 1977].

Salinity.—

- Can endure brackish water with salinity levels up to 13 ppt [Sublette et al. 1990].

General Behavior:

A schooling fish that congregates near the shore when spawning [Scott and Crossman 1973; Becker 1983]. Yellow perch eat zooplankton, aquatic insects, other invertebrates, fish, and fish eggs [Scott and Crossman 1973].

Reproduction:

Maturation.—Sexually mature at 2-4 years of age [Thorpe 1977]. Live up to 10 years and typically reach 150 to 300 mm TL [Scott and Crossman 1973; Thorpe 1977].

Spawning Requirements.—Spawn in spring when water temperatures range 6.7-12.2°C. Spawn in shallows of lakes and streams [Scott and Crossman 1973]. Spawning areas preferably have rooted vegetation, submerged brush, or fallen trees. Their relatively unspecialized requirements for spawning substrates allow them to use almost all slow-moving or static waters [Becker 1983].

Spawning Behavior and Biology.—No nests are constructed and no protection is provided for eggs or young [Scott and Crossman 1973; Becker 1983]. Eggs are laid in sheaths or strands up to 2.5 m long with clutch size ranging 950-210,000 eggs [Becker 1983]. Duration of spawning is < 2 weeks [Thorpe 1977].

Eggs and Young.—Eggs have a maximum diameter of about 2-3 mm. Incubation time is 8-10 d at usual spring water temperatures. Total length at hatching is 5.5-7.7 mm [Becker 1983].

Examples of Interactions with Native Colorado River Basin Fishes:

- None found.

Options for Control in the Upper Colorado River Basin:

Limit stockings. Presently, not an important threat to the endangered or other native fishes.

Walleye *Stizostedion vitreum*

Native Distribution:

From the Northwest Territories south to Georgia and from east of the Continental Divide to the Appalachian Mountains [Scott and Crossman 1973].

Distribution and Status in Upper Colorado River Basin:

Reproducing populations were established in reservoirs of the Duchesne River in the 1960's and 1970's. Fish have moved downstream into the Green River; rare or incidental. Elsewhere in the upper basin, the walleye is common in Lake Powell and rare or incidental in tributaries of the San Juan River [Tyus et al. 1982].

In a survey of CRB researchers, walleye ranked ninth (tied with flathead catfish and trouts) on a list of 28 nonnative fish species considered to adversely impact native fishes of the CRB and the southwestern United States. Suspected impacts included predation on young of native fishes (Colorado squawfish and razorback sucker mentioned specifically) and competition with native fishes (Colorado squawfish in particular) [Hawkins and Nesler 1991].

General Habitat:

There is Habitat Suitability Information for walleye [McMahon et al. 1984] that summarizes the species' habitat requirements and preferences.

Tolerate a wide range of environmental conditions. A coolwater species mostly restricted to large lakes and rivers [Scott and Crossman 1973; Colby et al. 1979]. Found in oligotrophic and eutrophic waters with the necessary shelter, spawning, and feeding resources [Becker 1983; Colby et al. 1979]. In rivers of the UCRB, walleye are captured in a variety of slow, shoreline runs, usually associated with emergent or bank vegetation [Tyus et al. 1990].

Examples of Environmental Factors Affecting Distribution or Abundance:

- Capable of tolerating a wide range of natural biotic and abiotic conditions [Colby et al. 1979].
- Avoid fast and turbulent water and prefer moderate currents and quiet water of lakes and rivers. Although, walleye move into swifter waters during the spawning season [Scott and Crossman 1973; Colby et al. 1979; Paragamian 1989].

- Mostly found in shallow water (1-15 m deep) where there is adequate shelter but will move to deeper water (27 m deep) to avoid light [Colby et al. 1979].

- Utilize various substrates, preferring cobble and gravel, and tolerate a wide range of turbidity [Colby et al. 1979; Becker 1983; Paragamian 1989].

- Year-class strength can be negatively impacted by rate of water warming (needs to $> 0.18^{\circ}\text{C}/\text{d}$), low oxygen, siltation, disease, predation, and strong winds and storms [Busch et al. 1975].

Temperature.—

- Found at water temperatures ranging $0-30^{\circ}\text{C}$; prefer $13-23^{\circ}\text{C}$ and avoid temperatures $> 24^{\circ}\text{C}$. Reported CTM is $33-34^{\circ}\text{C}$ [Scott and Crossman 1973; Colby et al. 1979].

Dissolved Oxygen.—

- Optimum D.O. concentrations are $> 5 \text{ mg/L}$; at concentrations $< 2 \text{ mg/L}$, walleye become stressed and death has been observed at 1.6 mg/L when exposed for several hours [Colby et al. 1979; Becker 1983].

Hydrogen Ion Concentration (pH).—

- Commonly found in water with pH 6-9 and have been sampled in waters with pH of 4, but the critical level for sustaining populations is 5.4 [Colby et al. 1979; Holtze and Hutchinson 1989].

General Behavior:

Crepuscular or nocturnal carnivore that utilizes zooplankton and invertebrates when young and a variety of fish when mature [Scott and Crossman 1973; Becker 1983].

Reproduction:

Maturation.—Males generally mature at 2-4 years of age, and females mature at 3-6 years [Scott and Crossman 1973]. Typically weigh 500-2,300 g and live 5-7 years in southern range and 12-15 years in northern range with a maximum reported longevity of 26 years [Colby et al. 1979].

Spawning Requirements.—Spawn in spring in a variety of habitats when temperatures range $5.6-11.1^{\circ}\text{C}$ [Scott and Crossman 1973]. Spawning habitats include shallow, rocky shorelines, gravel shoals, and flooded wetland vegetation of lakes and tributaries with gravel bottoms [Colby et al. 1979].

Spawning Behavior and Biology.—Spawning occurs over a 1-10 d period. No nests or protection are provided. Egg mortality can exceed 99%. Fecundity ranges 23,000-612,000 with averages of 29,000-82,000 [Scott and Crossman 1973; Colby et al. 1979].

Eggs and Young.—Eggs are demersal, initially adhesive, and have a maximum diameter of 1.5-2.0 mm. Typically, incubation time is 12-18 d. Total length at hatching is 6-9 mm [Scott and Crossman 1973].

Examples of Interactions with Native Colorado River Basin Fishes:

■ Identified fish found in stomachs of 61 walleye collected from the Green River, Utah, included the native flannelmouth sucker (other fishes found were nonnative) [Tyus and Beard 1990].

Options for Control in the Upper Colorado River Basin:

A long period of low-level, static residency in the upper basin suggests that numbers of walleye will not increase; however, the potential for predation on native fishes is a concern [Tyus and Beard 1990]. Possible factors limiting walleye in the upper basin include lack of large lentic habitats, high turbidity, inadequate forage, and lack of adequate spawning habitat. Options for ensuring that walleye do not become established in habitats of the endangered fishes include no future stocking (Colorado and Utah have stopped), increase angling harvest, and install fish barriers to prevent downstream movement from reservoirs.

Table 3.—Environmental factors affecting the distribution and abundance of nonnative, nonsalmonid fishes in the Upper Colorado River Basin (Note: temperatures following the @ symbol are acclimation temperatures; P = preferred; L = lethal; T = tolerated; A = avoid).

Species	Environmental conditions									
	Critical thermal maximum (°C)	Critical thermal minimum (°C)	Optimum/preferred temperature (°C)	Salinity (ppt)	DO	pH	TDS	Water velocity	Depths (m)	
<i>Dorosoma petenense</i>		4 @ 15		12-20 ppt (P)						
<i>Cyprinella lutrensis</i>	30.10-39.65*		<22.5 in Green River backwaters	≤10 ppt (P/T) ≥ 11 ppt (L)	1.5 ppm (T) ≤1.0 ppm (L)	7.1-7.4 (P) ≤4 & ≥ 11 (L)		low (P)	>0.15 m (P) in Green River backwaters	
<i>Cyprinus carpio</i>	31-36*	0.7	17-32*	≤17 ppt (P/T)	<0.1 mg/l (T/A)			low (P)	<33 m (A)	
<i>Gila atraria</i>			no preference			5-9.6 (P/T)			<5 m (P)	
<i>Gila copei</i>			10-23 (T/P)				need low turbidity		<0.3 m (P)	
<i>Hybognathus hankinsoni</i>	28.9	0			> 1.5 ppm (P/T)			low (P)	0.1 - 1.5 m (P)	
<i>Hybognathus placitus</i>			30 @ 21		5-9 mg/l/@21 °C 2 mg/l/@17 °C			low (P)	shallow (P)	
<i>Notropis stramineus</i>	33.1 @ 15		24-32		>1.4 ppm (T/P)	7.0-9.6 (T)		variable (T)	<34 m (P/T)	
<i>Pimephales promelas</i>	35	0	19.8-28.9*; <22.5 in Green River backwaters	<8.2 ppt (T/P)	>0.3 ppm (T/P)	5.5-9.8 (T)	385-7,036 mg/l (T/P); > 15,000 mg/l (L)	<0.15 m/s (P)	>0.15 m in Green River backwaters	
<i>Rhinichthys cataractae</i>	27.8		12.8-21		>0.3 ppm (T/P)		high turbidity (T)	0.4 m/s (P)	<0.3 m (P)	
<i>Richardsonius balteatus</i>	27 @ 14		16-19					low (P)		
<i>Semotilus atromaculatus</i>	25-33*	0.7-1.7*	26.4				clear to slightly turbid water (P)	low (P) swift (T)	young prefer depths <0.5 m; adults deeper	
<i>Catostomus ardens</i>	Tolerate a wide range of physicochemical conditions; specific limiting factors are unknown									
<i>Catostomus catostomus</i>	26.5 @ 14		11.6						6-30 m (P)	
<i>Catostomus commersoni</i>	31-32		10-27				wide range (T)	low (P)	≤46 m (P)	
<i>Ameiurus melas</i>	35 @ 23		21		>0.3 ppm (T/P)		100-600 ppm (P)	<0.4 cm/s (P)	<1.5 m (P)	
<i>Ameiurus natalis</i>			27.6		>0.3 ppm (T/P)		clear water (P) turbid water (A)		0.6-1.5 m (P)	
<i>Ictalurus punctatus</i>	33.5-35		26-29	2-11.4 ppt (T/P)	5 mg/l-sat. (P) <0.8 mg/l (L)	6.5-9.0 (P)	<100 ppm (P)	variable	variable	

Table 3.—Continued.

Species	Environmental conditions									
	Critical thermal maximum (°C)	Critical thermal minimum (°C)	Optimum/preferred temperature (°C)	Salinity (ppt)	DO	pH	TDS	Water velocity	Depths (m)	
<i>Esox lucius</i>	30.8* - larvae; 29.8* - juvenile; 32-35* - adults		19-21		≤ 0.2 mg/l (L)	3.5-9.5 (T/P)	turbid water (A)	<44 cm/s (T/P)	<3 m (P)	
<i>Fundulus zebrinus</i>				high (T/P)			high (T/P)	variable	<0.15 m (P)	
<i>Gambusia affinis</i>	35.4 @ 15	1.5 @ 15	31		does not limit			low (P)	near water surface (P)	
<i>Morone chrysops</i>	33.5		28-29.5				clear water (P)		within 6 m of surface	
<i>Morone saxatilis</i>	29 - adults	11-12 - larvae	20-28 - young and subadults; 16-22 - adults	elevated hardness beneficial to larvae	>6 mg/l - larvae and juveniles (P); 2-3 mg/l - adults (P)	7-9.5 - larvae (P); <6.9 (L)		low (P), except during spawning	15-30 m (P) in Lake Powell	
<i>Lepomis cyanellus</i>	33-36		16.9-30.6*		>1.5 mg/l (T/P)		variable (T)	low (P)	<1.5 m (P)	
<i>Lepomis macrochirus</i>	35.5-36.5		28-32	<3.6 ppt (P)	>3.0 mg/l (P)	6.5-8.5 (P)		<0.10 cm/s (P)	entire water column	
<i>Micropterus dolomieu</i>	37 (independent of acclimation temperature)		20-31*		>6.0 mg/l (P)	> 5.1 (T/P)	clear water (P)	≤20 cm/s (P)	>0.45 m (P)	
<i>Micropterus salmoides</i>	36-39*		27.2-30	<0.9 ppt (T/P)	>1.5 mg/l (T/P)	3.9-11 - adults (T/P); 5-10 - young (T/P)	clear water (P)	low (P)	<6 m (P)	
<i>Pomoxis annularis</i>	31		27-29		>3.3 ppm (P/T)	6.2 - 9.6 (P/T)	variable (T)		vary with season	
<i>Pomoxis nigromaculatus</i>	none established		24-30	<4.7 ppt (P/T)	>0.3-1.4 mg/l (P/T)		clear (P)	10-60 cm/s (P)		
<i>Etheostoma exile</i>					>2 mg/l (P/T)		clear water (P)	low (P)		
<i>Etheostoma nigrum</i>	30-32		21-23		>0.2 ppm (T/P)		clear water (P)	low/mod. (P)	shallow areas (P)	
<i>Perca flavescens</i>	26-33		20	<13 ppt (T/P)	>0.25-2.25 mg/l (T/P)		clear water (P)	<60 cm/s (P/T)	< 9.2 m (P)	
<i>Stizostedion vitreum vitreum</i>	33-34		13-23		>0.5 mg/l (P)	6-9 (P)	variable turbidity (T)	low/mod. (P)	1-1.5 m when shelter is present	

depending on acclimation temperature

Table 4.—Control options for nonnative, nonsalmonid fishes in the Upper Colorado River Basin.

Species	Degree of threat to recovery of native fish species	Control Options			
		Mechanical: electrofishing, netting, barriers, sport/harvest	Chemical	Biological: prevent additional introductions, predation, disease (parasites)	Physicochemical: (habitat manipulations) temperature, flow, etc...
<i>Dorosoma petenense</i>	no threat				X
<i>Cyprinella lutrensis</i>	existing threat	X ^a	X ^b	X	X
<i>Cyprinus carpio</i>	existing threat	X	X ^d		
<i>Gila atraria</i>	no threat	X ^c	X	X	X
<i>Gila copei</i>	no threat				
<i>Hybognathus hankinsoni</i>	no threat				
<i>Hybognathus placitus</i>	no threat				
<i>Notropis stramineus</i>	existing threat	X ^a	X	X	X
<i>Pimephales promelas</i>	existing threat	X ^a		X	X
<i>Rhinichthys cataractae</i>	no threat				
<i>Richardsonius balteatus</i>	potential threat	X ^a		X	X
<i>Semotilus atromaculatus</i>	no threat				
<i>Catostomus ardens</i>	no threat		X		
<i>Catostomus catostomus</i>	no threat	X			
<i>Catostomus commersoni</i>	potential threat	X	X		
<i>Ameiurus melas</i>	potential threat			X	
<i>Ameiurus natalis</i>	no threat			X	
<i>Ictalurus punctatus</i>	existing threat	X		X ^f	X
<i>Esox lucius</i>	potential threat	X	X	X	X
<i>Fundulus sciadicus</i>	no threat				
<i>Fundulus zebrinus</i>	no threat			X	
<i>Gambusia affinis</i>	no threat			X	X
<i>Morone chrysops</i>	no threat	X		X	
<i>Morone saxatilis</i>	no threat	X	X		
<i>Lepomis cyanellus</i>	existing threat	X	X	X	
<i>Lepomis macrochirus</i>	no threat	X		X	
<i>Micropterus dolomieu</i>	potential threat	X	X	X ^a	X
<i>Micropterus salmoides</i>	potential threat	X	X	X	X
<i>Pomoxis annularis</i>	no threat	X	X	X	X
<i>Pomoxis nigromaculatus</i>	no threat			X	
<i>Etheostoma exile</i>	no threat				
<i>Etheostoma nigrum</i>	no threat				
<i>Perca flavescens</i>	no threat			X	
<i>Stizostedion vitreum vitreum</i>	potential threat	X		X	X

^a - temporary removal possible

^b - would rebound rapidly

^c - in littoral areas

^d - would lose native fish

^e - bass tapeworm

^f - channel catfish virus disease

DISCUSSION

Abiotic and biotic factors govern the composition of fish assemblages. In the UCRB, these conditions have been altered primarily through diversions and impoundments that altered flows, temperature, turbidity, and habitat (Behnke and Benson 1983). These changes have facilitated an increase in nonnative fish species that are better adapted for these conditions (Table 3) and resulted in a decline of the native fishes (Behnke and Benson 1983; Moyle 1986). In most circumstances, development of sport fisheries and subsequent introduction of nonnative fishes was used to partially justify building impoundments.

Selective-control projects in the UCRB must start with a review of biology of the species (Figure 2; Table 3). For example, many of the nonnative cyprinids in the UCRB do well in low-velocity (Table 3), nursery habitats of native species, and red shiner, sand shiner, and fathead minnow complete their entire lifecycles in these habitats (Tyus et al. 1982; Haines and Tyus 1990; see Species Accounts). Therefore, physicochemical approaches are the most promising control option (Table 4) and potentially the only available means of reducing cyprinids. Many of the centrarchids prefer clear water conditions (Table 3), consequently the highly turbid conditions that are present in the UCRB have (to a degree) limited centrarchid abundance. However, because many of the centrarchids are primarily lentic species (Table 3), low-velocity/flooded-bottomland habitats augment and

concentrate centrarchids. Because centrarchids are in predictable locations, they can be targeted for mechanical removal (Table 4).

Any attempts to selectively control fish in the UCRB should be approached carefully and fully evaluated with documentation of species abundance before and after the removal attempt. Targeting a single species without regard to its relationship with other fishes could result in additional or different problems and interactions (Wiley and Wydoski 1993). For a control measure to be successful in the UCRB, it needs to be accompanied with a alteration of habitat that favors native species.

Historic fish-control efforts have achieved success in reducing undesirable fish. These efforts, however, have generally been confined to isolated reservoirs, lakes, and small drainages. No attempts to control fishes have been made at a scale as large as the UCRB which drains over 284,000 km² (Tyus and Karp 1991; Figure 3). Fish control is feasible within the upper basin. We define fish control, however, as reducing a specific negative interaction with a corresponding positive response from the desired species. This control may be limited by spatial and temporal constraints.

*NONNATIVE SPECIES NOT CONSIDERED A THREAT TO ENDANGERED OR OTHER
NATIVE FISHES IN THE UCRB*

The following nonnative species are not presently considered a threat to the endangered or other native fish species in the UCRB due to their present low abundance (Table 2) and/or sub-optimal habitat and environmental conditions that limit these species (see Species Accounts; Table 3): threadfin shad, Utah chub, leatherside chub, brassy minnow, plains minnow, longnose dace, creek chub, Utah sucker, longnose sucker, yellow bullhead, plains topminnow, plains killifish, western mosquitofish, white bass, striped bass, bluegill, white crappie, black crappie, Iowa darter, johnny darter, and yellow perch. If reaches in the upper basin support abundant, localized populations of these species, some control options are available (Table 4). Although the above species are not presently considered threats to endangered fishes, their abundance may increase if existing conditions change.

*NONNATIVE SPECIES CONSIDERED POTENTIAL THREATS TO ENDANGERED OR
OTHER NATIVE FISHES IN THE UCRB.*

Although the following species are only locally problematic, their abundance may increase if existing conditions change.

Cyprinidae.—Redside shiner is rare or incidental in reaches occupied by young of endangered fishes and probably has minimal,

if any, negative effects on these fishes. However, it is common or abundant in upper reaches of the Yampa, Green, Duchesne, and Dirty Devil rivers and may impact young of other native fishes. Physicochemical approaches have the potential to reduce redbside shiner abundance (Muth and Nesler 1993; Table 4). Correlative evidence has demonstrated that relative abundance of redbside shiner is negatively affected by high river discharges and associated lower water temperatures. However, unlike the red shiner, sand shiner, and fathead minnow, higher discharges resulted in an earlier initiation of spawning for the redbside shiner, probably due to the species preference for cooler water (Muth and Nesler 1993). Biological control also has the potential to control redbside shiner (Table 4). This cyprinid is vulnerable to predation; consequently, stocking Colorado squawfish (a piscivore) in some localities to supplement existing wild stocks could facilitate reducing redbside shiner abundance.

Catostomidae.—Widespread distribution (Tyus et al. 1982; Table 2) and tolerance to a wide range of environmental conditions (Table 3; Scott and Crossman 1973; Becker 1983) suggest that the white sucker has the potential to spread in the UCRB, indicating the importance of continued monitoring of this species. High turbidity, suboptimal temperatures, and competition with other fishes may be limiting the abundance of white sucker in habitats of endangered fishes. However, hybridization with flannelmouth sucker and bluehead sucker is a concern (Wick et al. 1981, 1985, 1986; Valdez et al. 1982a,

1982b). Control of white sucker can best be accomplished through mechanical and chemical control methods (Table 4) by targeting spawning aggregations (between June and July) for netting and electrofishing. Chemical treatment in upper reaches of rivers or in reservoirs where white sucker is common would also reduce its abundance.

Ictaluridae.—Although the black bullhead is rare or incidental in reaches of the Colorado, Duchesne, Green, San Juan, White, and Yampa rivers (Tyus et al. 1982; Table 2), evidence of predation by black bullhead on young Colorado squawfish has been documented (Tabata et al. 1965; Osmundson 1987). This fish also ranked seventh on a list of 28 nonnative species considered to adversely impact native fishes of the CRB and southwestern United States (Hawkins and Nesler 1991). Mechanical removal attempts (e.g., electrofishing and netting) should be focused on localized river reaches where high concentrations are known.

Esocidae.—The northern pike is widely distributed in the upper basin, but its occurrence is rare or incidental (Tyus et al. 1982; Table 2), except in the Yampa and upper Green rivers where the species is routinely collected during ISMP sampling (McAda et al. 1994). Despite low numbers in most occupied areas, piscivorous habits combined with evidence of increasing populations and sympatry with endangered fishes in backwater habitats make northern pike one of the nonnative species of increasing concern (Tyus and Beard 1990; Hawkins and Nesler 1991). Biological control (preventing further introductions) of

northern pike has begun. Colorado and Utah have discontinued stocking programs for northern pike.

Several mechanical options are available for reducing abundance of northern pike including increasing fishing pressure, installing barriers to prevent fish from moving downstream from reservoirs, netting, and electrofishing. Because the northern pike is rare to incidental in the upper basin (Table 2), removal by netting and/or electrofishing would be effort intensive and probably futile. These techniques should only target localized reaches where northern pike are abundant or where spawning aggregations (during late winter and early spring) occur.

Centrarchidae.—Centrarchids with the potential for detrimental impacts on endangered and/or other native species include largemouth bass and smallmouth bass. The largemouth bass is not widely distributed within the upper basin; it is abundant in Lake Powell and rare or incidental in the mainstem Colorado and San Juan rivers and in Flaming Gorge Reservoir (Tyus et al. 1982; Table 2). High turbidity, variable flows, competition, and absence of quality spawning areas contribute to the low numbers and small size of largemouth bass in the upper basin. However, piscivory on native fishes (Hendrickson and Brooks 1987; Osmundson 1987) combined with an affinity for low-velocity habitats (Table 3; Heidinger 1976; Becker 1983) are reasons for concern over the impacts that largemouth bass might have on young native fishes.

Smallmouth bass also is a species of increasing concern in the UCRB (Hawkins and Nesler 1991). This species has a scattered distribution along the Green River in Utah, but is rarely sampled, except near Ouray where it is common. The smallmouth bass is rare or incidental in reaches of the Yampa, Gunnison, and Duchesne rivers and in Flaming Gorge and Navajo reservoirs (Tyus et al. 1982; Table 2). However, this species is now routinely collected in the Yampa and upper Green rivers during ISMP sampling (McAda et al. 1994). High turbidity, competition, predation, erratic flows, and suboptimum spawning conditions have contributed to limiting smallmouth bass in the upper basin. However, because adult smallmouth bass are piscivorous and are moving into habitats of the endangered fishes, the potential for detrimental impacts on native fishes exists.

Control measures directed at largemouth and smallmouth bass, as well as any centrarchid, should begin by preventing downstream movement from impoundments (e.g., installing fish barricades to eliminate escapement). Stocking in off-channel impoundments should be eliminated until effective isolating screens are installed. Smallmouth bass probably move into upper basin rivers from protected off-channel spawning areas (Osmundson and Kaeding 1991), therefore the elimination of stocking and isolating off-channel habitats from river channels would facilitate a reduction in smallmouth bass abundance.

Increasing fish harvest and targeting known concentrations in localized river reaches for netting, electrofishing, and/or

chemical treatment (if appropriate consideration is given to minimizing potential loss of native fishes) also are viable control options for reducing centrarchid abundance (Table 4).

Largemouth and smallmouth bass are primarily lentic species that have adapted to low-velocity habitats (Table 3), and would probably be adversely impacted by the higher flows used for cyprinid control (Bestgen and Propst 1989). Minckley and Meffe (1987) found that centrarchids were reduced in abundance or completely eliminated after major flooding in unregulated Arizona streams. However, this has not been documented in the UCRB because many centrarchids are in low abundance, making evaluation of decreases in abundance difficult.

Percidae.—The percid of increasing concern in the UCRB is the walleye (Hawkins and Nesler 1991). The species has moved downstream from reservoirs on the Duchesne River and into the Green River where it is rare to incidental. Elsewhere in the upper basin, the walleye is common in Lake Powell and rare or incidental in tributaries of the San Juan River (Tyus et al. 1982; Table 2). A long period of low-level, static residency in the upper basin suggests that numbers of walleye will not increase, but the potential for predation on native fishes is a concern (Tyus and Beard 1990). Control of walleye in the upper basin has begun by eliminating stocking (Colorado and Utah have stopped). Additional control options include the installation of fish barriers to prevent downstream movement from reservoirs and

increasing angling harvest in assessible, localized river reaches.

NONNATIVE SPECIES CONSIDERED EXISTING THREATS TO ENDANGERED OR OTHER NATIVE FISHES IN THE UCRB

Cyprinidae.—Of the 11 nonnative cyprinids in the UCRB, red shiner, common carp, fathead minnow, and sand shiner are considered to be existing threats to the endangered fishes and/or other native fishes. In a survey of CRB researchers, these four cyprinids were ranked in the top six on a list of 28 nonnative species considered to adversely impact native fishes of the CRB and southwestern United States (Hawkins and Nesler 1991). Nonnative cyprinids do well in low-velocity, nursery habitats of native fishes, and red shiner, sand shiner, and fathead minnow complete their entire lifecycles in these habitats (Table 3; Tyus et al. 1982; Haines and Tyus 1990).

Physicochemical approaches are the most promising control option and potentially the only available means of reducing prolific and potentially detrimental nonnative cyprinids in the UCRB (Osmundson and Kaeding 1991). Correlative evidence has demonstrated that relative abundance of red shiner, sand shiner, and fathead minnow is negatively affected by high river discharges and associated lower water temperatures (McAda and Kaeding 1989a; Osmundson and Kaeding 1989, 1991; Valdez 1990; Muth and Nesler 1993), suggesting that management of flow regimes to approximate natural hydrographs and periodically providing

above average magnitudes in spring and summer discharges would suppress their abundance. Muth and Nesler (1993) also found that moderate-high daily mean discharges were associated with later initiation of spawning and a shorter spawning season for the red shiner, sand shiner, and fathead minnow.

Cause and effect relationships between discharge and cyprinid abundance still need to be determined. It is important to (1) determine flow magnitude and duration required for control, (2) determine the frequency of flow manipulations required for control, (3) determine what effects temperature regimes associated with flow regimes have on cyprinid abundance, (4) quantify cyprinid abundance before and after flow/temperature manipulations, and (5) quantify the effects of flow/temperature manipulations on native fishes. Evidence to date has demonstrated that native fishes will not be negatively impacted by the above flow regimes (Meffe 1984; Minckley and Meffe 1987; Muth and Nesler 1993).

Biological control also has the potential to control red shiner, sand shiner, and fathead minnow. These cyprinids are vulnerable to predation; consequently, stocking Colorado squawfish (a piscivore) to supplement existing wild stocks could facilitate reducing their numbers.

Because common carp are tolerant to a wide range of environmental conditions (Table 3), efforts to eradicate or even control them are virtually impossible (Cross 1967). Exploitation of the commercial and sport possibilities of common carp is the

most promising solution for controlling this species (Sigler 1958; Becker 1983), but this approach would be virtually impossible in the upper basin given the inaccessibility of much of the basin. Spawning aggregations (peak spawning between early June and early July) in localized river reaches could be targeted for electrofishing and netting (Table 4).

Ictaluridae.—Channel catfish is the nonnative believed to be the greatest threat to native fishes in the UCRB (Hawkins and Nesler 1991), largely due to predation and diet overlap with endangered fishes. Several studies have documented predation of channel catfish on native fishes, especially larvae and juveniles (Coon 1965; Kaeding and Zimmerman 1983; Marsh and Brooks 1989; Karp and Tyus 1990b; Muth and Beyers in review). Channel catfish has demonstrated a relentless ability to recover rapidly and propagate in the upper basin, so control will be exceedingly difficult. Control should begin with the elimination or reduction of stockings or stocking only sterile fish.

Electrofishing and netting are viable tools to reduce abundance of channel catfish (Table 4), but the species is common to abundant throughout most of the upper basin so a tremendous amount of effort would be required. Mechanical removal attempts should focus on localized river reaches where high concentrations are known.

Reducing older age classes, as well as the overall abundance of channel catfish, would reduce predation on native fishes. In the Green River, growth of channel catfish was less than that

reported within its native range (Tyus and Nikirk 1988). Slow growth may be due to limited resources, suboptimum temperature regimes, short growing seasons, and other unfavorable riverine conditions. If angling for channel catfish was increased in areas where they are common/abundant, larger age classes (and consequently predation on native fishes) may be further reduced. Gerhardt and Hubert (1991) concluded that an increase in annual exploitation rate from 1% to 22% in the Powder River, Wyoming, would shift channel catfish population structure and abundance of fish to smaller size classes and reduce the number of fish ≥ 300 mm by 75%.

Management of flow regimes to approximate natural hydrographs and associated lower water temperatures and turbidity should further limit channel catfish growth and abundance (Table 3). In the Green River, periodic die-offs of channel catfish may be caused by heavy input of silt during flash floods (Tom Chart, Utah Division of Wildlife Resources, personal communication).

Centrarchidae.—The centrarchid that is an existing threat in the UCRB is the green sunfish. In a survey of CRB researchers, green sunfish tied for fifth on a list of 28 nonnative fish species considered to adversely impact native fishes of the CRB and the southwestern United States (Hawkins and Nesler 1991). Of the six centrarchids in the upper basin, the green sunfish is the most abundant and best suited for adapting to present environmental conditions (Table 3). Piscivorous habits of green sunfish (Osmundson 1987; Marsh and Langhorst

1988; Muth and Beyers in review) and their relatively high abundance and sympatry with native fishes in low-velocity nursery habitats (Carlander 1977; Becker 1983) are reasons for concern.

Control measures directed at green sunfish, as well as any centrarchid, should begin by preventing downstream movement from impoundments (e.g., installing fish barricades to eliminate escapement). Stocking in off-channel impoundments should be eliminated until effective isolating screens are installed. Green sunfish probably move into upper basin rivers from protected off-channel spawning areas (Osmundson and Kaeding 1991). Eliminating stocking and isolating off-channel habitats from river channels would facilitate a reduction in abundance of green sunfish. Targeting spawning aggregations for netting, electrofishing, and/or chemical treatment (if appropriate consideration is given to minimizing potential loss of native fishes) also are viable control options for reducing abundance of centrarchids (Table 4).

The green sunfish is primarily a lentic species that has adapted to low-velocity habitats (Table 3) and would probably be adversely impacted by higher flows used for cyprinid control. Minckley and Meffe (1987) found that centrarchids were reduced in abundance or completely eliminated after major flooding in unregulated Arizona streams; however, this has not been documented in the UCRB.

RECOMMENDATIONS

1. *IMPLEMENT SELECTIVE CONTROL MEASURES.*

Selective control techniques should start on a small spatial scale and build when results warrant.

Mechanical Control.—Fishing regulations should be liberalized in areas where nonnative game species (1) have the potential or are known to have detrimental impacts on native species, and (2) are accessible to anglers. These species include: common carp, ictalurids, northern pike, and centrarchids. For example, smallmouth bass and green sunfish have been identified as important predators on age-0 Colorado squawfish in nursery habitats. Removal of these species via angling has the potential of lessening predation pressure on young Colorado squawfish in these areas. Similarly, the northern pike has also been shown to present a potential threat to Colorado squawfish (Crowl et al. in press). However, northern pike exclusively consumed age-1 Colorado squawfish in that study. Thus, enhanced fishing pressure in areas where this age class of fish is known to occur (e.g., Ouray-Green River; 15-mile reach, downstream of Palisade-Colorado River) should be explored.

Mechanical removal in localized reaches through the use of traps, seines, gill nets, and electrofishing is a viable technique for controlling many nonnative species in the UCRB. Because many species that are susceptible to mechanical removal

techniques have a spotty distribution in the upper basin (Table 2), removal efforts should be targeted at areas of known, large, localized concentrations (including spawning aggregations). For example, centrarchids are potential target species because they are typically found in predictable locations in low-velocity habitats. Control of white crappie in Navajo Reservoir should be attempted to reduce the chance of their movement into the San Juan River. Concerns of anglers will need to be addressed when the abundance of high-interest species are reduced. Alternative angling opportunities would need to accompany reduction of any popular gamefish species.

Nonnative fishes along with young Colorado squawfish and razorback sucker also are in high concentrations in the inflow area to Lake Powell. We believe that interaction with nonnative fishes in the inflow (most likely via predation) prevent the native fishes from recruiting into the riverine population. Therefore, it is important to understand, and if possible control these interactions.

Barriers that are currently preventing expansion of nonnative fishes in the upper basin (e.g., barriers on the Gunnison and Colorado rivers) should be maintained. Additional barriers should be constructed on reservoirs and off-channel impoundments to prevent the escapement of target nonnative fishes from these areas. For example, barrier construction on the Duchesne River reservoirs would prevent walleye from moving downstream. Construction of barriers could aid in the reduction

of northern pike, walleye, and many of the centrarchids that appear to be expanding in river reaches near tributary confluences.

At a smaller scale, predator exclusion cages and fences that restrict access of larger fishes in backwaters are proving effective at decreasing densities of nonnative predators and enhancing age-0 Colorado squawfish survival in localized areas (Crowl and Lentsch, personal observation). Excluding nonnative predators from backwaters in nursery-habitat areas should be evaluated as a methodology for enhancing first-year survivorship, a suspected bottleneck period for most endangered native species in the UCRB.

Chemical Control.—Extreme care should be taken during all chemical treatment projects in the upper basin to prevent the loss of native fishes, such as those experienced during the treatment of Flaming Gorge tailwaters (Holden 1991). Chemical treatment of reservoirs, which contain a high abundance of detrimental nonnative species and do not have endangered fishes, would eliminate the expansion of nonnative fishes downstream of the reservoirs. Localized river reaches with existing barriers, particularly tributary streams (e.g., tributaries of the Duchesne River) to prevent the reinvasion of nonnative species should also be considered candidate locations for chemical reclamation. Again, chemical treatment of river reaches should be in locations with few endangered fishes.

Isolated areas (e.g., flooded bottomlands, headwater stream reaches, etc.) with high concentrations of nonnative species also could be targeted for chemical reclamation. A treatment protocol in the spring, prior to spawning of native fishes in isolated areas, could be an effective method for controlling the abundance of nonnative fishes in nursery areas. This is especially applicable to aggregations of nonnative fishes recently observed in inundated areas (Crowl and Lentsch, observed in June, 1995). If these fish are colonizing these areas from the surrounding river reaches, chemical treatment could significantly decrease densities of nonnative fishes at the river-reach scale. Documentation of what species are utilizing isolated areas (e.g., floodplain areas) before chemical treatment should be completed to ensure that they are not being utilized by native fish at the time of treatment.

Biological Control.—Biomanipulation of nonnative species within the upper basin was not considered an alternative for control in this paper. However, stocking of piscivorous natives, such as the Colorado squawfish, may reduce smaller nonnative species (e.g., many of the cyprinids) in the upper basin that may compete with native fishes at early life stages. For example, adult red shiner are believed to have negative impacts on larval Colorado squawfish and razorback sucker (Karp and Tyus 1990a; Beyers et al. 1994; Muth and Beyers in review). Stocking large, piscivorous Colorado squawfish or bonytail in these areas (not beyond reach carrying capacity) may be an effective biological

control strategy for small nonnatives. Before the stocking of endangered fishes, a stocking plan needs to be developed to ensure that the appropriate genetics concerns are addressed.

The most obvious and effective manner of biological control is to adhere to the current draft stocking policies of nonnative fishes in the upper basin region, which limit future nonnative stocking. Limiting nonnative sport fish stocking within the basin is one of the few comprehensive control measures that can be taken.

Physicochemical Control.—The management of flow regimes to approximate natural hydrographs and periodically provide above-average magnitudes in spring and summer discharges will help suppress the abundance of prolific cyprinids, such as red shiner and fathead minnow. To quantify effects of flow/temperature manipulations, flow releases from reservoirs should coincide with pre- and post-release monitoring to determine the effects on cyprinids.

In conjunction with this effort, current efforts by Lentsch et al. (SOW 1995, Nonnative fish management in the Green River) and Pfeifer et al. (SOW 1995, Selective removal of nonnative fishes from the Gunnison River within Colorado) should be continued and enhanced at a basin-wide scale. Specifically, data associated with abundance of nonnative cyprinids should be correlated with location- and year-specific flow regimes (peak, duration and seasonal variance) to confirm whether cyprinid abundance varies inversely with flow (see McAda and Kaeding

1989a; Osmundson and Kaeding 1989; Valdez 1990; Muth and Nesler 1993). Quantifying the abundance of nonnative and native species before and after flow/temperature manipulations will be critical to determine: (1) the flow magnitude and duration required for control; (2) the frequency of flow manipulations required for control; and (3) what effects the temperature regimes associated with the above flow regimes have on nonnative species abundance.

Water-level drawdowns in reservoirs to expose spawning areas will impact nonnative species that rely on littoral reservoir habitat for spawning (e.g., Utah chub and many of the centrarchids) and reduce their abundance within reservoirs. For example, water-level drawdowns during late spring/early summer in Kenny and Elkhead reservoirs would facilitate a reduction in centrarchid abundance.

2. *ADOPT A TEMPORALLY AND SPATIALLY SEQUENCED APPROACH THAT CONTAINS AN EVALUATION OF ALL CONTROL ATTEMPTS.*

Small river reaches, isolated flooded bottomlands, reservoirs, etc. that are located in high-priority river reaches with abundant detrimental nonnative species (species labeled as existing threats) should be targeted first. If species in the potential threats category (1) are abundant in localized reaches, (2) begin to increase in abundance in localized river reaches or (3) appear to be impacting native fishes within localized river reaches, then control attempts should be directed at these

species in the reaches they are impacting. Documentation of species abundance before and after removal attempts is critical to quantify effectiveness. After removal, techniques can be refined to increase efficiency and larger areas can be targeted if control results are positive (i.e., reduced target species abundance, positive native response, etc.).

3. DEVELOP AN UNDERSTANDING OF THE POTENTIAL RAMIFICATIONS AT THE COMMUNITY LEVEL OF A SELECTIVE CONTROL ACTION.

Targeting a single species for selective control without regard to its relationship with other fishes could enhance negative fish interactions (Wiley and Wydoski 1993). Studies that address the overall metabolism of the river system should be initiated to determine the food-resource partitioning, bottlenecks, and community level dynamics (i.e., prey switching as prey abundance changes, predator swamping, etc.) that occur in this system (Minckley 1982). Although direct predation is the most obvious interaction between native/nonnative fishes, the utilization of common, limited resources is ultimately the limiting factor associated with fish biomass productivity in the system. As long as the majority of the most available food resources are currently supporting nonnative fish biomass, the recovery of specific native fishes will be an impossibility. System-wide bioenergetics approaches, coupled with detailed

foraging-behavior studies will be essential to unraveling the now complex foodweb of the UCRB.

4. *DEVELOP A MONITORING AND EVALUATION PROGRAM TO ASSESS SELECTIVE CONTROL AND OTHER RECOVERY PROGRAM ACTIONS ON THE FISH COMMUNITY.*

The number of studies and activities associated with nonnative/native interactions has recently increased (see the 1994-1996 work plans). Many of these are now going beyond describing the types of interactions that occur between nonnative and native fish and actually seek to affect these linkages. We strongly recommend that such studies be continued, expanded, and accompanied by an evaluation plan. Although it is hoped that such activities will result in an increase in the recruitment of target native species, that particular measured response could be 1-10 years in the future given the population dynamics of predator/prey interactions involving long-lived prey. Showing significant decreases, albeit localized ones, in abundance of nonnative fishes as a result of specific management activities is an essential first step toward our understanding and ultimate modification of the upper basin fish community.

Although additional localized attempts are conducted to manage nonnatives, current site-specific monitoring and the implementation of a basin-wide monitoring program for nonnatives will contribute greatly to our understanding of localized and

basin-wide nonnative community dynamics. Our understanding of meso-scale community dynamics is still lacking. This scale of inquiry is especially important given the concomitant direction of the Recovery Implementation Program in flooded bottomland restoration. The greatest biomass in existing low-velocity habitats in the Colorado River is comprised of red shiner, fathead minnow, common carp, and channel catfish (Tom Nesler, CDOW, personal communication). Nonnative density and distribution data from the Jensen-Sand Wash area of the Green River suggest that tributary areas and other low-velocity (standing water) habitats also attract high densities of nonnative fishes. These areas typically have the highest diversity of nonnative species as well. More importantly, these areas often harbor age-0 and/or juvenile fishes of important species such as green sunfish, channel catfish, and smallmouth bass, suggesting that these areas are used for reproduction and rearing (Crowl and Lentsch, personal observation).

5. *DO NOT CREATE HABITATS THAT ENHANCE NONNATIVE SPECIES.*

We suggest a very careful, thoughtful approach to floodplain inundation (and other similar management activities) be employed that will allow a thorough evaluation of the impact of such activities on the density and distribution of nonnative fishes and overall community structure. All such activities must include a careful evaluation of nonnative fishes prior to,

during, and after management activities to establish whether these approaches will differentially increase abundance of nonnatives. Because many of the important nonnative species are littoral-zone species (see species accounts), a large increase in these species with the addition of low-velocity, structurally complex habitats is expected.

6. *MAINTAIN BARRIERS THAT PREVENT EXPANSION OF THE RANGE OF NONNATIVE SPECIES.*

Barriers that are currently preventing expansion of nonnative fishes in the upper basin (e.g., barriers on the Gunnison and Colorado rivers preventing nonnative range expansion and/or selective native fish passage) should be maintained.

7. *DEVELOP AN APPROACH TO ADDRESS SOCIAL AND RECREATIONAL CONCERNS TOWARDS CONTROL OF NONNATIVE FISHES.*

If control of nonnative fishes is deemed necessary in locations with popular sport fisheries, alternative angling opportunities should be developed and publicized. Caution should be taken, however, before these alternate locations are developed. They should not be located within areas of critical habitat for the endangered fishes; including tributary locations (e.g., Duchesne River) within the 100 year flood plain to prevent future conflicts with recovery of native fishes. Any disturbance

or removal of nonnative sport fisheries should be compensated to ensure social and recreational activities involving sport fish are protected.

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